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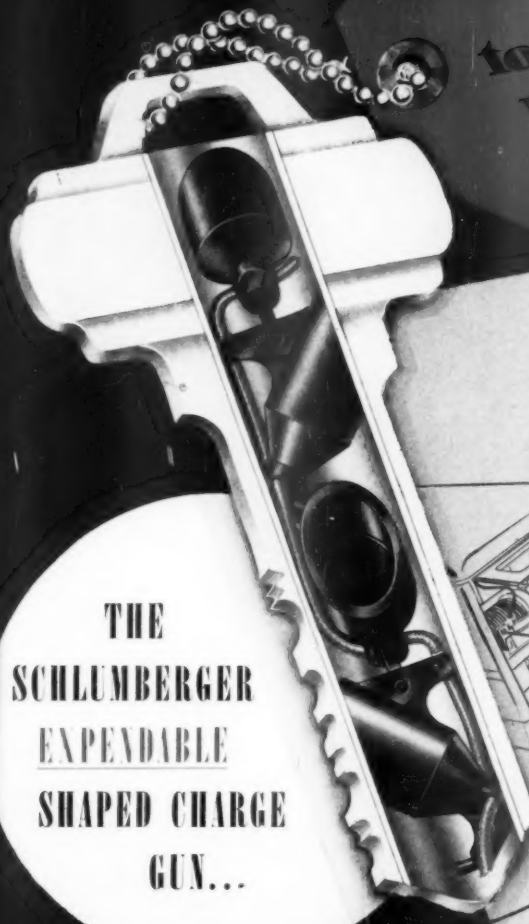

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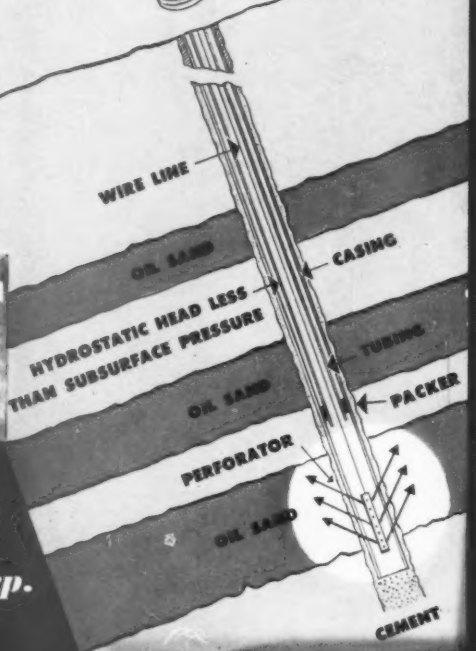

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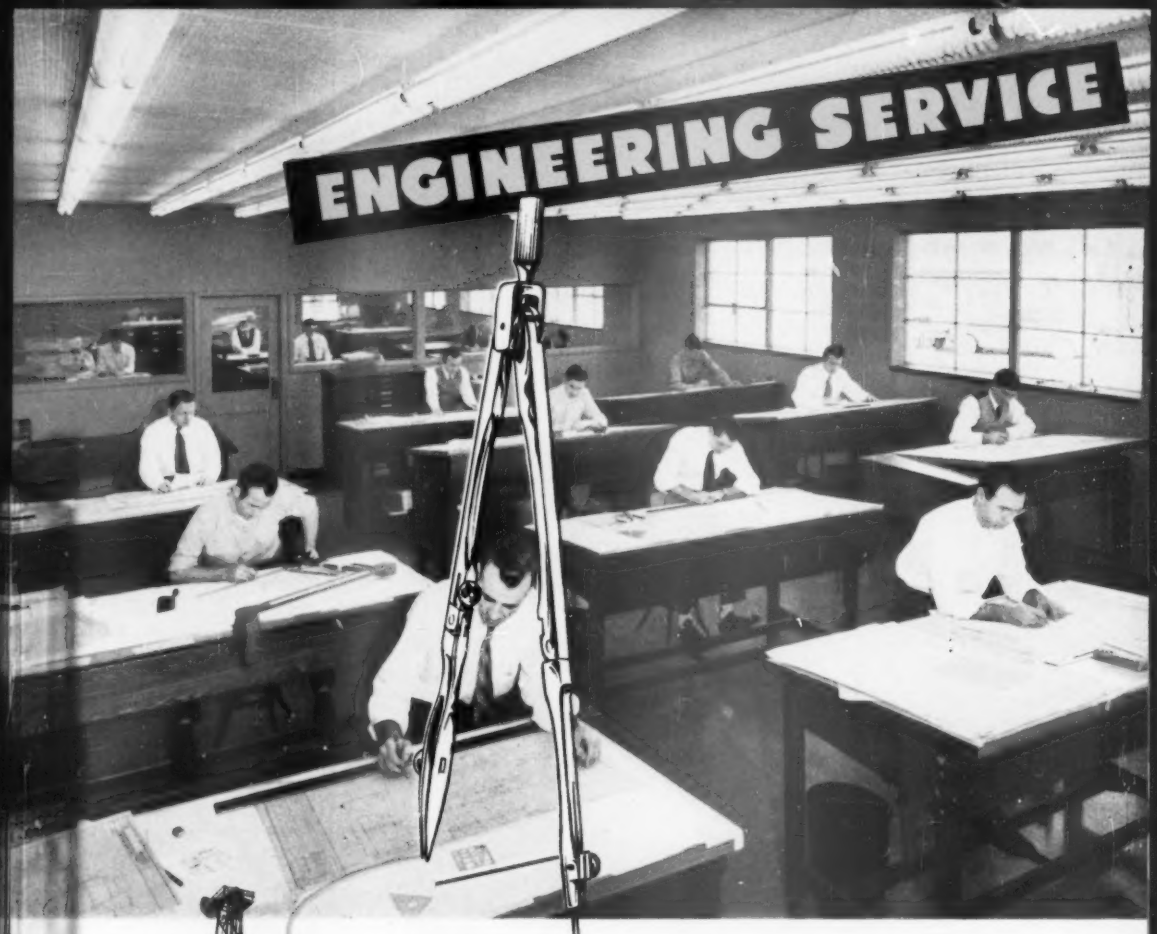

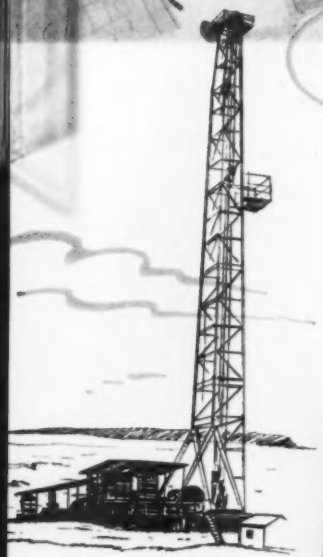

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On the Cover — Dynamite blast set off by a seismic party silhouettes against the snow-whitened Montana plains near Lewiston. Dramatic current developments here and in the neighboring Dakotas and Canada have elicited the article "The Market for Williston Basin Oil" beginning on page 10. *Photo by Anthony Linck, courtesy Cities Service Co.*

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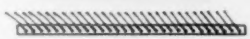

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Guest Editorial

"Never So Good"

By H. H. Kaveler

Petroleum Consultant

Member, AIME

It has been said that American citizens have never before "had it so good." The standard of living and the comforts of life are multiplied to a very large segment of the population. What is more important, however, is the prospect, barring an extreme upset, that the comforts of Americans will increase to new and higher levels as we go forward under the American system of enterprise and harness the new scientific knowledge to economic advantage in what some call the future atomic age.

In the heated political campaign just closed, credit for America's economic and social gains was loudly claimed but no one found opportunity to deal with the basically important question: "How does America come to have it so good?"

Some say our standard of living is the product of government; that we would not prosper unless some particular political philosophy were followed. No statement could be farther from the truth. The social and the economic progress of this country is the result of the effort and the energy of individual citizens working under a system of free and competitive enterprise. That is the one thing that distinguishes the United States of America from all other systems or methods of government. Other nations lead, or have led, in science and research. Other nations have citizens who labor and toil. Other nations have industry. But nowhere, except in the U.S.A., has there been that binding together of science, research, industry and effort by free competitive enterprise. And as a consequence there has been nowhere the social progress that is America's.

The important fact for America is that, regardless of the political party in power, the U. S. system of free enterprise could and would bring a bountiful standard of living. Political parties, if they could be distinguished, differ only to the extent that they help, or hinder, the normal accomplishments of competitive industry.

The petroleum industry in America is composed of approximately 35,000 distinguishable units engaged in the business of finding, developing, producing, transporting and selling petroleum. The primary task of each competitor is to make petroleum products available to consumers at lower cost. The reward to the competitor is a greater share of the market and possibly a greater profit from his effort.

If any of us in the petroleum industry has a television set, a power lawnmower, an automobile, or other of the many things Americans like to own, it is because our neighbors and fellow citizens are engaged in a competitive effort to produce such things at costs low enough for us to afford. We reciprocate by giving the public low-cost petroleum products. It is the productivity of competitive industry and the effort of each employed person to produce more things at lower cost that creates the social and economic well-being of the American people. None of our comforts come as a consequence of government. The purpose of government is to provide the rules that protect one citizen from injury by another and no more than that. Government cannot create wealth. It exists only as an expense and a burden. Joe Doakes, a citizen, can meet his debts by creating wealth. He may produce a bushel of potatoes, a barrel of crude oil, or build a television set. He may sell the product of his labor and have a margin of income over cost to meet his debts. Government has no such means to serve economic demands. It can meet debt only by confiscating a part of the wealth of citizens.

Some have said that this election year was a year of decision. Other years to come will be so labeled. They are years of decision but not in the sense of choosing one political party as superior to another. Rather the decision made is in the sense of choosing between government as a servant and government as a master. When government is the servant we give prime importance to the system of free and competitive enterprise and recognize that in the final analysis it is the labor of citizens that produces under that system all the things that make America great.

The AIME represents a group of technologists who owe their professional existence to the system of private enterprise. Technology is the very essence of competitive industry. Without free competition there would be little, if any, technology. ★ ★ ★

Vast new reserves are being discovered daily in oildom's most exciting boom of the past two years. But what happens to this new crude supply after it comes out of the ground?

The Market for Williston Basin Oil

By John G. Winger
The Chase National Bank of New York

ABSTRACT

This paper attempts to define the probable market for Williston Basin crude oil. The total market area available to this oil is considered to lie mainly within the borders of PAW District 2. Estimates of future supply and demand in this region indicate a growing deficiency of crude oil which parellels the anticipated growth in the Williston Basin productive capacity; hence Williston production could fill the void.

The local market, embracing North Dakota and portions of Montana, South Dakota and Minnesota, is considered to be large enough and will grow sufficiently to absorb all the Williston production for the foreseeable future. The supply which will be thus replaced will be absorbed elsewhere in District 2.

INTRODUCTION

The discovery of oil in the Williston Basin has aroused keen and widespread interest. This is one of the largest sedimentary basins in Continental North America and includes portions of Montana and the Dakotas in the United States as well as Saskatchewan and Manitoba in Canada. Sporadic attempts to discover oil have been made since 1923; but there was not an intensive search until oil was actually found in April 1951. It is now one of the most active areas in the United States or Canada. Results have been encouraging and oil has been found in North Dakota, Montana, Saskatchewan, and Manitoba. The search continues and must for many years in order to explore the more than one hundred million acres in this huge geological province. After studying the potentialities of the area, some geologists have estimated that more than 2½ billion bbl will ultimately be discovered.

The Williston question raises these questions: (1) Will there be a market for Williston Basin oil? and (2) if so, how large will it be? In this paper an attempt is made to find the answers.

Although part of the Basin extends into Canada, we are concerned here only with that portion which lies within the United States and all references in this paper are to that portion.

For the purpose of locating the Williston Basin in respect to its potential market area, frequent reference will be made to the five Petroleum Districts set up during World War II. (See Fig. 1.)

Paper presented at the Petroleum Branch Fall Meeting in Houston, Tex., Oct. 1-3, 1952.

MARKETABILITY OF RESERVES

As we all know, crude oil reserves have a certain value, the degree of which is determined by a number of desirable characteristics. Among the most important is that of marketability.

To have a positive value, oil reserves should be located so as to promise delivery to the final consumer at a competitive price either at the present time or in the foreseeable future. To possess marketability, the reserves must be near major consuming areas or else there should be cheap and adequate transportation facilities available. If neither is present, the finding and lifting costs must be low or there must be a scarcity of supply in order for the oil to enter the market place at a competitive level. One or more of these characteristics has been possessed by most of the nation's major discovery areas.

WILLISTON BASIN'S LIMITATIONS

As the first rush of excitement following discovery of Williston Basin oil begins to subside, the question of marketability assumes ever increasing importance. If the reserves are shortly developed to such a degree that a major producing area results, is there a ready market for the oil?

Williston Basin oil is lacking in some desirable characteristics. It does not have access to low-cost water transportation nor are there heavily populated consuming areas close at hand. North Dakota, South Dakota, and Montana are among the most sparsely populated states in the nation and the bulk of Minnesota's population is located in the southern portion of the state within reach of the Chicago refining center. On the basis of current information, finding and development costs are not sufficiently low to afford any particular advantage in bringing the oil to market. The next question, then, seems to be: Is the potential market of such size as to permit Williston Basin oil, despite its handicaps, to capture a sizeable portion?

EXTENT OF WILLISTON BASIN'S POSSIBLE MARKET

Because of the geographic location of the Williston Basin in respect to other producing areas and to population centers, it seems most likely that, if its oil is to find a market, it must do so within District 2. Surplus production in Canada, which

is trying to find a market of its own, will effectively prevent Williston oil from moving north and, indeed, Canadian production may provide effective competition by moving down into District 2. Transportation economics, plus the competition of other producing areas, precludes the movement of Williston oil to the East Coast, while the producing areas to the south prevent its moving in that direction. If it sought a market to the west, it would collide head on with a productive surplus from District 4 seeking a market to the east. There have been some suggestions that the oil be sent to the Pacific Northwest to supplement the faltering California supply. But the Trans Mountain Oil Pipe Line, carrying Canadian oil to the Pacific Northwest, will have been built and in operation before Williston Basin reserves are developed sufficiently to support a pipe line. The maximum volume carried by this line, plus California's production, appears likely to prove sufficient to satisfy estimated demand in the Pacific Northwest for some time. The remote possibility that the tidelands issue might be resolved could alter the supply outlook in California.

Therefore, it appears that Williston oil will have to find its market in District 2, and, if it is to be more than a local market, it must move to the eastern half of the District because over half of the area's population is located within just four states — Illinois, Indiana, Michigan, and Ohio (Fig. 1). The per capita consumption of petroleum products is greater in the more heavily populated states which further emphasizes the necessity to move the oil there. Fig. 2 shows the location of existing refinery capacity within District 2, each dot representing 10,000 B/D capacity. The location of this capacity indicates that Williston Basin crude, seeking other than local markets, would have to travel at least as far as the Chicago refinery center. Strictly in terms of distance, the Mid-Continent producing area has an advantage in reaching the larger market area and some production from Districts 3 and 4 could also compete favorably.

LOOKING AHEAD

To find answers to our questions, it is necessary that an attempt be made to forecast petroleum supply and demand for a number of years ahead. This must be done for the United States and for each of the five districts in order that the available supply for District 2 may be determined.

A forecast can be most useful if it is always remembered that it is but a direction indicator — not an exact course — and represents, after careful deliberation, what appears to be the most likely road at the present time.

In preparing our estimates, we have tried to determine the normal growth pattern. Looking back for two decades, there seems to have been no real period of normalcy but, between the highs and lows of petroleum supply and demand, there does appear a growth trend. It is the extension of this trend

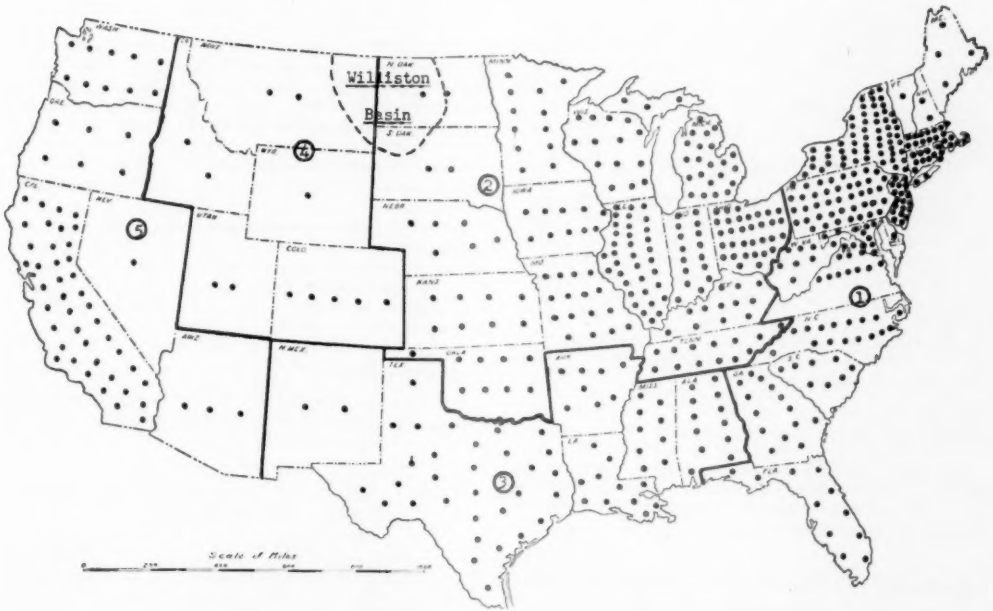


FIG. 1—POPULATION OF THE UNITED STATES BY PAW DISTRICTS. EACH DOT REPRESENTS 250,000 PEOPLE.

FIG. 2—REFINERY CAPACITY IN DISTRICT 2 BY LOCATION. EACH DOT REPRESENTS 10,000 B/D OR FRACTION THEREOF.

that we have attempted to determine and apply in this study. We have assumed no major wars or depressions nor has allowance been made for early public and private use of any new source of energy such as atomic power.

DEMAND IN DISTRICT 2

In Table I we show our estimates of demand for crude oil in District 2 and the United States at the close of three five-year periods.

It should be emphasized that the figures in Table I represent the demand for crude oil alone — not the total petroleum demand. Imports of refined products and the production of natural gas liquids share in satisfying the total demand. Natural gas liquids are expected to play an increasingly important role and, therefore, the demand for crude will not increase quite as rapidly as that for all oils.

RATE OF INCREASE SLOWER IN DISTRICT 2

The indicated rate of increase in crude oil demand in District 2 is somewhat less than that for the nation and there are a number of reasons why this is so. It may be well to discuss some of the more important.

Population

For each decade of the twentieth century the rate of population increase in District 2 has not kept pace with that for the nation. In 1900 the region had 41 per cent of the nation's inhabitants but by 1950 the percentage had dropped to 35. A further decline was registered as of July 1951, and by 1965 it is expected that the district may have no more than 33 per cent. In the decade ended in 1950, the area had shown the smallest increase of all five districts, registering a gain of about 10 per cent *vs* 15 per cent for the nation. Since the 1950 census, population in District 2 has increased about one per cent a year compared with one and one-half per cent for the nation.

There is a definite relationship between population and petroleum demand and the slower rate of gain in population in this area has been accompanied by a similar slower rate of gain in petroleum demand. We are aware of no unusual conditions which could be expected to alter such trends in the next few years.

Gasoline Demand

District 2 has failed to keep pace with the nation in the rate of gain in motor vehicle registrations. Moreover, there are fewer persons per vehicle, which suggests that the area

Table I — Estimated Demand for Crude Oil in District 2 and the United States

	District 2		United States	
Year	Demand Thousand B/D	Change During 5-Year Period Per Cent	Demand Thousand B/D	Change During 5-Year Period Per Cent
1950	1,700	+26	5,907	+20
1955	2,120	+25	7,700	+30
1960	2,530	+19	9,300	+21
1965	2,800	+11	10,500	+13

may be closer to a saturation point than is the nation, and this would also seem to indicate a continued lag in future years. As might be expected, the rate of gain in gasoline consumption has also been smaller.

The lag in motor vehicle registrations is quite significant because gasoline demand comprises more than 50 per cent of the total petroleum demand in District 2. In no other district is the gasoline proportion so high and for the entire country it represented but 41 per cent in 1951.

Tractors, which account for a major portion of non-highway gasoline consumption, are also quite important, the area having more than 50 per cent of the United States total. Although the number in use has increased rapidly in recent years, the rate of increase has been lower than for the rest of the country.

Of all the fuels consumed in tractors, gasoline represents about 80 per cent and, since it is so important a part of District 2's petroleum demand, the future trend in tractor numbers, like motor vehicles, is important. Moreover, the use of liquefied petroleum gas as a tractor fuel has been expanding by leaps and bounds in the past few years. The advantages of this fuel, which have caused farmers to accept it so enthusiastically, are expected to result in its further widespread use with correspondingly lower crude oil requirements.

For several years the number of farms in District 2, as well as for the entire country, has been declining but the average farm size has increased. This increase in size has been smaller in District 2, however, which probably accounts for the slower increase in tractor numbers.

Middle Distillate Demand

District 2 has been the scene of a very rapid increase in the number of central heating oil burners as well as other oil burning equipment, the rate of gain surpassing that for the nation. The consumption of middle distillates for heating purposes has also shown a greater percentage increase than has the nation.

The use of light fuel oils for purposes other than heating has also exhibited rapid growth. Sales of diesel oil in particular have boomed and may be expected to continue to do so as long as more and more locomotives and other diesel engines are brought into use.

A large potential market for oil-burning equipment in District 2 portends further growth in middle distillate demand but the outlook is not entirely bright. Future expansion in the use of natural gas will doubtless have a moderating effect upon the growth of oil demand. While a shortage of steel and conflicts over what constitutes a proper price for gas may for a time slow down expansion, the consensus seems to be that the increase in natural gas use will be very substantial in future years. Not only will there be greater sources of native supply seeking a market but the possibility of more natural gas being exported from Canada to the United States is considered to be very real. The desirable aspects of home heating with natural gas are being more widely recognized and future growth in its use is certain to have a pronounced impact upon demand for heating oil throughout the country.

Thus, while the demand for light burning oils may be expected to continue growing, it will likely be at a slower rate than in the post-war years.

Residual Fuel

Like the light fuel oils, heavy residual fuel demand in District 2 has been growing in recent years, but the rate of increase has been lower than that for the nation. Most of the gain in consumption is due to greater use for heating and industrial purposes.

The outlook for heavy oil is less optimistic than for light oils and the impact of more widespread use of natural gas is apt to be proportionately greater. Residual has been in oversupply in the Midwest for some time and future years may bring greater effort to reduce the yield of this product.

In view of the fairly pronounced trends in consumption and without indications of reversal in the near future, it seems reasonable to expect future growth in petroleum demand to proceed at a somewhat slower rate in District 2 than in the nation as a whole.

SUPPLY IN DISTRICT 2

Having established what is believed to be a reasonable estimate of future demand in District 2, it next becomes necessary to examine the sources of supply to satisfy that demand.

The region now produces about 60 per cent of its crude oil requirements and obtains the balance from the Gulf Coast and the Rocky Mountain areas. The Gulf Coast accounts for approximately 90 per cent of the outside crude supply. In addition to the crude oil shipments, a substantial volume of refined petroleum products is brought in, again principally from the Gulf Coast region. Altogether, about half of the demand for all oils is satisfied by supplies from outside the district.

As we look to the future, several questions arise: (1) Will the area's productive capacity, exclusive of that of the Williston Basin, be sufficient to continue supplying 60 per cent of the crude oil requirements? (2) Will the crude oil imports from other districts continue to grow or will they decline? (3) What of the product imports — will growing demand in other districts siphon them off?

PRODUCTIVE CAPACITY OF THE AREA

Opinions differ regarding the ability of District 2, excluding the North Dakota portion of the Williston Basin, to expand crude oil productive capacity. The area was able to increase its reserves by seven per cent in 1951, somewhat less than the nation's gain. Additions in the past decade have also lagged behind the nation's and increases in production rates were comparatively small.

Most of the individual producing states within the district have increased their reserves in the past decade. Oklahoma made the largest actual gain, followed by Illinois and Kansas. More modest gains were made by Indiana, Michigan, and Kentucky.

The greater part of the production gain in the last 10 years occurred in Kansas and Oklahoma, with Indiana and Kentucky making smaller gains. Production in Illinois and Michigan has declined for several years.

It appears that future production increases, excluding that from the Williston Basin section, are most likely to result from further development in Oklahoma and Kansas. New areas showing promise are the Anadarko Basin in Oklahoma and the Julesburg Basin covering portions of Kansas and Nebraska. Barring discoveries of major proportions, it seems unlikely that the district's productive capacity will be sufficient to continue supplying 60 per cent of its crude oil requirements.

CRUDE IMPORTS FROM OTHER DISTRICTS

Future demand for oil produced in District 3 is expected to increase substantially in the next few years. District 1 is the major market and there are indications of large future

growth there as well as locally in District 3. New outlets to deepwater, plus the possibility of a large diameter pipe line to the West Coast, will remove some of the pressure for West Texas oil seeking a market in District 2.

Despite the prospects of growing demand for the oil of District 3, it is thought that the supply will more than keep pace. Increases in petroleum availability are expected to be the greatest in the nation. Moreover, imports of foreign oil into District 1 will doubtless expand along with demand in that area. Tidelands oil, given the right political atmosphere, may also become a factor in the supply picture.

There is now a surplus of productive capacity in District 4 which appears likely to grow more rapidly than demand, creating increased pressure for that oil to move eastward.

Thus, because of growing availability of outside supplies of crude oil and since transportation systems and markets have long been established, it is thought that such sources will continue to supply at least 40 per cent of District 2's crude requirements.

PRODUCT IMPORTS

The volume of refined products moving into District 2, it is believed, will also be expanded in future years. Again, there are well-established lines of transportation and markets. A greater volume of product imports, of course, lessens the district's demand for crude oil.

CANADIAN OIL A FACTOR

There is now a large volume of shut-in capacity in Canada due to lack of markets. Current estimates of growth in demand indicate that there will continue to be a surplus of productive capacity. In order to avoid delay in the further development of Canadian oil there may be an effort to enter the United States market within District 2. Canadian oil traveling via the Interprovincial Pipe Line may enter the markets where it would be in direct competition with oil from the Williston Basin. While Canadian oil would be handicapped by a somewhat greater distance of travel and a tariff barrier, it would have the advantage of several years' headway in development, a pipe line already in operation, and, judging from the results so far, lower cost of production.

Therefore, while Canadian oil is not now one of the sources of supply, it may become so.

DEFINING THE MARKET

In Table II the estimates of future crude oil supply and demand in District 2 are brought into focus.

Table II — Estimated Crude Oil Supply and Demand Balances in District 2

	1955	1960	1965
	(Thousand B/D)		
Estimated Crude Requirements	2,120	2,530	2,800
Crude Supply:			
Local Production (excl. Williston Basin)	1,200	1,300	1,375
Shipments from Other Districts	860	1,020	1,120
Total Supply	2,060	2,320	2,495
Balance: Additional Crude Supply Required	60	210	305

Table III — Williston Basin's Productive Capacity Relative to Local Demand

Year	Productive Capacity (Thousand B/D)	Local Demand (Thousand B/D)
1955	90	200
1960	210	260
1965	305	300

A deficiency of crude supply is shown which indicates an early and growing need for Williston Basin oil, in other words, a ready market. But, we would also like to know if this volume represents the size of the total market available. The answer to this is mainly dependent upon the Williston Basin's ability to produce in excess of the district's supply deficiency.

If Williston production were to make up all the deficiency indicated for each year in Table II, proven reserves of the Basin would need to approximate 330 million bbl in 1955, 1,150 million in 1960, and 1,670 million in 1965. In this calculation a 15-to-1 ratio of reserves to production is used. While Williston's reserves will probably exceed 330 million bbl in 1955, many geologists feel that the figures used for 1960 and 1965 represent the probable maximum which may be expected from normally intensive development based upon current estimates of the oil ultimately to be discovered. Thus, the probable productive capacity of the Basin would appear to limit the size of its market to a volume no greater than the growing deficiency of crude in District 2.

Williston oil's local market, which includes North Dakota and portions of Montana, South Dakota, and Minnesota, will probably be able to absorb all the Williston production, at least until 1965. Estimated demand in this area is compared with the probable productive capacity in Table III.

As the Williston productive capacity grows and is able to satisfy a larger portion of the local demand, the supply sources now serving this area will be replaced. But, because of the growing supply deficiency indicated in Table II, this replaced supply will be absorbed elsewhere in District 2.

Before the Williston production can be utilized by its so-called local market, it will be necessary to build adequate refinery capacity within the area.

CONCLUSIONS

At the outset of this paper we asked the questions: (1) Will there be a market for Williston Basin oil? (2) If so, how large will it be? Our investigations lead to these answers:

(1) There will be a market. It will be primarily a local market which includes North Dakota and portions of Montana, South Dakota, and Minnesota. Local refinery capacity will need to be built.

(2) The local market will be large enough to absorb all the productive capacity which current estimates of the size of the Basin indicate to be reasonable. By 1965 this volume is expected to approach 300,000 B/D.

But our conclusions must be qualified at least to this extent — the market, thus defined, appears probable only if Canadian competition in District 2 remains negligible and crude oil shipments from other districts do not exceed the current level of 40 per cent of District 2's requirements. Should these two factors assume greater proportions, Williston oil would have to compete more vigorously for a market. ★ ★ ★

New Telephone: STerling-5835

Petroleum Branch Office Moves to New Home

The Petroleum Branch offices in Dallas have now been moved to their new permanent home at 800 Fidelity Union Bldg.

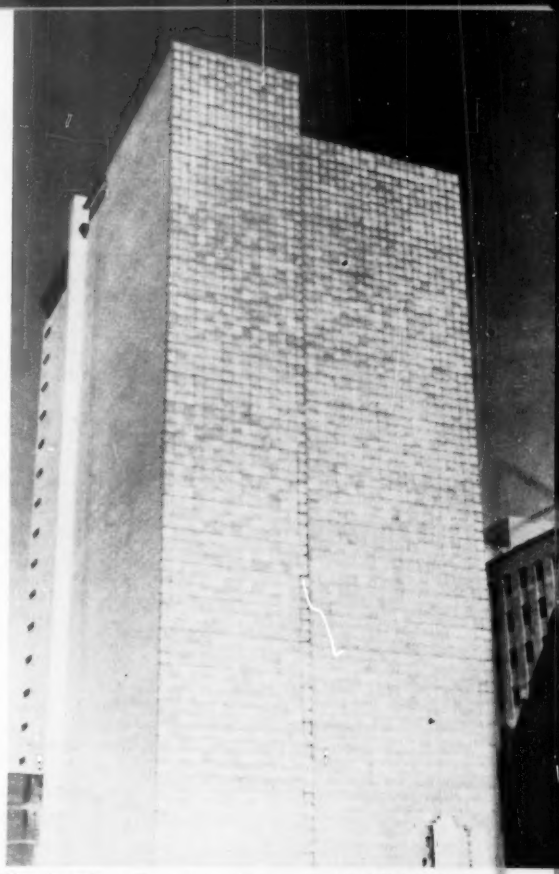
Selection of the new quarters was based primarily on accessibility to members. The building, still under construction and scheduled for completion in January, is just three blocks north of the central hotel area, and about midway between the east and west limits of the downtown district.

The L-shaped space now occupied is on the northwest corner of the building. Windowed offices of the individual staff members for the Branch and the JOURNAL OF PETROLEUM TECHNOLOGY are along the north side. Along the windowless west wall are an equipment and work room, containing mimeograph, addressograph, and mailing and shipping facilities, and a store room.

Decorative scheme of the offices has been planned to create an atmosphere of modest refinement, in keeping with the nature of a professional society. Floors of the private offices are covered in a conservative gray carpeting. The walls are painted a soft green, complementing the gray-blond woodwork.

One wall of the reception room will contain a photo-mural montage of members' photographs. Included in the mural will be pictures of all former Chairmen of the Petroleum Division and Branch. An expenditure from the Special Projects Fund for improvements in the quarters was authorized by the Executive Committee.

The move on Nov. 22 was the fourth for the Petroleum Branch office since its establishment in Dallas six years ago. Continually expanding activities and several increases in the staff have resulted in the need for greater space. It is anticiplated that the new space of about 1,200 sq ft will be adequate for some years to come.



New Petroleum Branch quarters are in the Fidelity Union Bldg., seen here from the south side at Pacific and Bryan Sts. In the background at right is the Atlantic Bldg.

Entering the suite, a visitor will be greeted by Receptionist Mrs. Joanne Moran. Open doorway shows a portion of the Secretary's office, and door at right leads to office of the Assistant Secretary. Editorial, accounting, equipment and store rooms are out of picture to the left.

Opened in the home of William H. Strang, Secretary of the Branch from 1946 to 1950, the office was moved to a location on South Ervay and then to the Continental Bldg. on Commerce St. By the spring of 1951, six permanent staff members were cramped into a space of about 800 sq ft. In addition, several temporary employes were needed during the summer to prepare preprints for the Fall Meeting. Additional space was not available at that time in the same building. In May, 1951, space of about 1,000 sq ft was obtained in the Trinity Universal Bldg., away from the center of town and at a lower per-foot rental. A 13-month lease was signed, with the idea that this time would be sufficient for determining future needs in space and the relative advantages or disadvantages of the location.

Members who came to Dallas during this time felt that the Branch headquarters were too far from the downtown area, and that a visit to this location was difficult to work into a crowded business schedule. A thorough investigation of both older buildings and those under construction indicated that space in the Fidelity Union Bldg. would be the most favorable. The Branch has signed a five-year lease, with option to renew.

It is hoped that the new offices will become a true professional home for petroleum engineers. Members and their guests are urged to visit the new Branch headquarters and to use its facilities at any time. ★ ★ ★

Technical Note 147—

REDUCTION IN PERMEABILITY WITH OVERBURDEN PRESSURE

I. FATT, MEMBER AIME, AND D. H. DAVIS, CALIFORNIA RESEARCH CORP., LA HABRA, CALIF.

Oil bearing rocks, usually found at depths of 2,000 to 10,000 ft, are elastically deformed by overburden pressure. Although the change in porosity with pressure in a number of example rocks has been shown to be small,[1] it was thought that overburden pressure might have a significant effect on permeability. This note presents results of an investigation to determine the magnitude of the change in permeabilty with pressure.

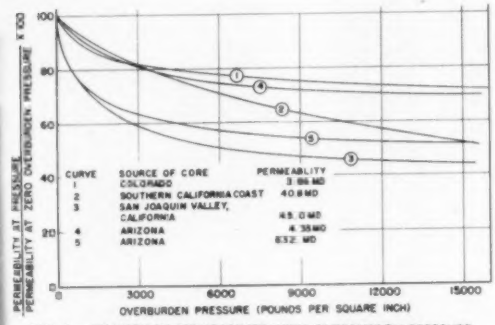


FIG. 1 — CHANGE IN PERMEABILITY WITH OVERBURDEN PRESSURE.

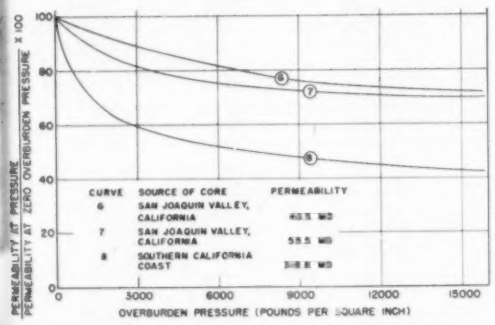


FIG. 2 — CHANGE IN PERMEABILITY WITH OVERBURDEN PRESSURE.

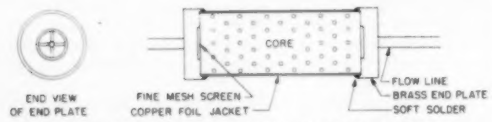


FIG. 3 — DETAILS OF CORE MOUNTED IN COPPER FOIL JACKET.

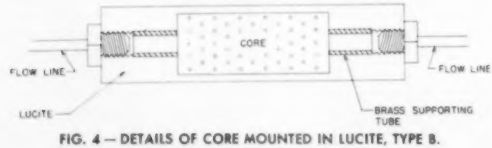


FIG. 4 — DETAILS OF CORE MOUNTED IN LUCITE, TYPE B.

In routine core analysis, permeabilities are measured on rock samples which are not under overburden pressure. If permeablity measured in this way differs from permeabilities measured under overburden pressure, a systematic error is introduced into well productivity calculations. The experiments described in this report were made to determine the magnitude of the change and thus to give an estimate of the error introduced into the calculations. The error introduced by the neglect of the change in permeability when overburden pressure is removed may account for part of the difference between well productivity calculated from core analysis and the actual well productivity.

The results obtained in this investigation have only qualitative significance because of the difficulty in reproducing in the laboratory the stress conditions on the rock buried in the earth. The assumption which is usually made is that the rocks in the earth are under a uniform pressure equal to the weight per unit area of the vertical overburden column from the rock in question to the surface of the earth less the pressure of the liquid in the pores of the rock. For an overburden consisting of sandstones and shales (of assumed average specific gravity of 2.3) and for a liquid pressure equal to the pressure in a salt water column (of specific gravity 1.0) reaching from the rock to the surface, the resulting net pressure on the rock is approximately 0.56 psi per ft of depth.

EXPERIMENTAL METHOD

Clean, dry sandstone core plugs one in. in diameter and about three in. long were mounted in a copper foil jacket as shown in Fig. 3 or molded in a Lucite jacket as shown in Fig. 4. All cores except those labeled "2" in Fig. 1 and "8" in Fig. 2 were measured in the copper foil jacket. Cores "2" and "8" were measured in the Lucite jacket.

The jacketed core was placed in a high pressure hydraulic bomb in which the liquid pressure outside the jacket could be raised to 15,000 psi. Flow lines from the core were brought out of the bomb through special fittings in the bomb head and connected to a laboratory type gas permeameter. Measurements were made with nitrogen gas; the maximum mean gas pressure in the core was 16.1 psia.

RESULTS

The specific permeability of sandstone decreases with increase in overburden pressure. Most of the decrease takes place over the range of zero to 3,000 psi overburden pressure. If the net pressure on the rock is assumed to be 0.56 psi per ft of depth as discussed above, 3,000 psi of overburden pressure is equivalent to about 5,000 ft of overburden. At 3,000 psi overburden pressure, the permeability of the eight sandstone core samples tested ranged from 59 to 89 per cent of the permeability without overburden pressure. Figs. 1 and 2 show the permeability reduction as a function of overburden pressure. The permeability of the eight cores without overburden pressure ranged from 4.35 md to 632 md; these permeabilities are listed in Figs. 1 and 2.

REFERENCES

1. Carpenter and Spencer: "Measurements of Compressibility of Consolidated Oil Bearing Sands," U. S. Bureau of Mines, R.I. 3450, (1940).

★ ★ ★

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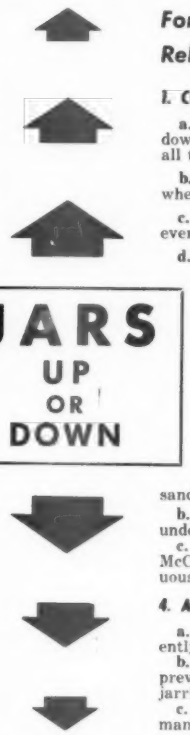

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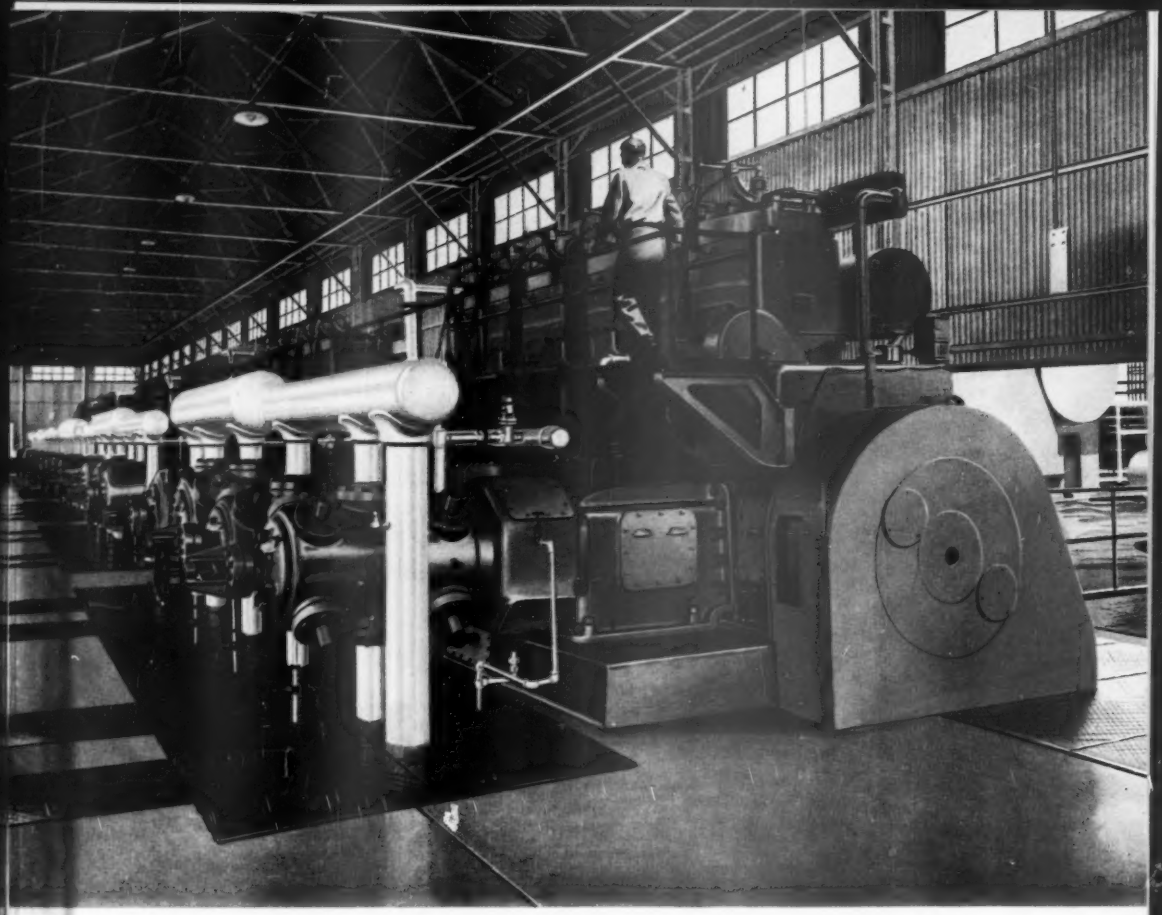

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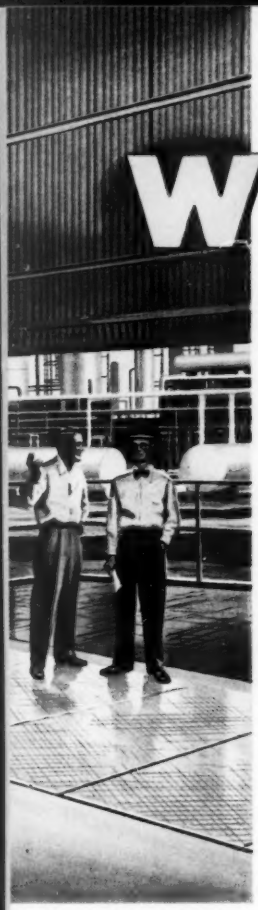

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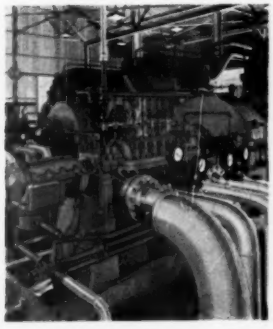
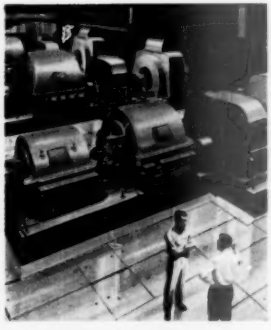


Pacific Pumps, Inc., *Huntington Park, Calif.* Centrifugal pumps, deep oilwell plunger pumps, hot oil and boiler feed pumps.



Roots-Connersville Blower Division, *Connersville, Ind.* Rotary positive blowers, gas pumps; centrifugal blowers, exhausters; positive displacement meters.

Security Engineering Division, *Whittier, Calif., Dallas, Tex.* Rock bits, reamers, casing scrapers, reamer rock bits, coring bits, Securaloy.

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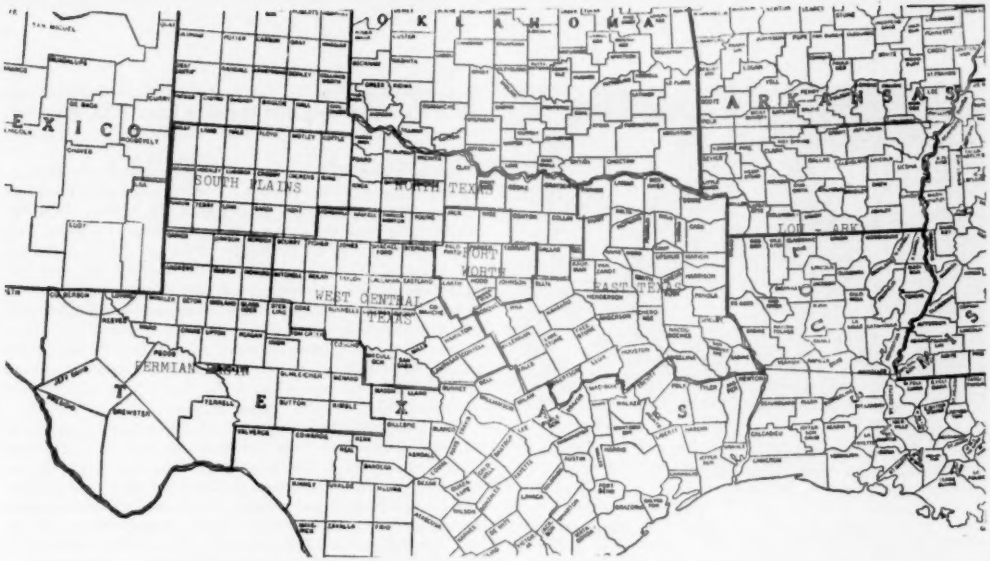


Four new Local Sections are shown above along with established sections which underwent changes. The new sections are Lou-Ark, Fort Worth, West Central Texas and South Plains. The East Texas, North Texas and Permian Basin Sections gave up territory to make room for the new sections.

Four New Local Sections Organized During 1952

As the petroleum industry grows, so grows the Petroleum Branch of AIME. As evidence of this expansion, four new petroleum Local Sections have been organized within the year 1952 on written request of ten members or more from each proposed Section. The South Plains, West Central Texas, Fort Worth, and Lou-Ark Local Sections, organized to serve the ever-growing number of members of the AIME, will combine with the already-established groups to total 14 Sections, two Chapters, and four Sub-Sections which fall under the administration of the Petroleum Branch.

Formerly a Sub-Section of the Permian Basin Local Section, the newly-formed South Plains Local Section will encompass essentially the same territory that it held as a Sub-Section. Since its formation as a Sub-Section in 1950, the present South Plains Local Section has had increasing membership interest, primarily in the vicinity of Lubbock, has held exceptionally good programs and, in effect, has functioned as a Local Section since its origin. It will hold its regular meetings in Lubbock, with Norman Lamont of Texas Technological College as chairman. Other officers are: D. D. Bowersock, vice-chairman; W. M. Jones, vice-chairman; and Marvin Willis, secretary-treasurer.

NORMAN LAMONT

F. W. NUSSBAUMER

With the official formation of the West Central Texas Local Section in Abilene, on Sept. 17, an important part of the petroleum industry for the Abilene area was completed. It encompasses 23 counties lying generally northeast and southwest from Abilene. Fifty persons attending the initial meeting in February appointed Fred W. Nussbaumer, Halliburton Oil Well Cementing Co., as chairman. The Section presently has 45 regular AIME members and a number of local affiliates. Other officers are Jack L. Coulson, Warren Petroleum Co., first vice-chairman; Dalton Moore, Jr., Wimberly Association, second vice-chairman; J. A. Jenkins, Stanolind Oil and Gas Co., secretary-treasurer. Directors are Lloyd Kaltenberger, Chemical Process Co.; A. J. Evans, Warren Petroleum Co.; and Hassell E. Hunter, Rhodes Drilling Co.

Formation of a new Fort Worth Local Section was approved by the Petroleum Branch Executive Committee at the Houston Fall Meeting and the AIME Board of Directors on Oct. 15. The new unit was originally a portion of the North Texas Section, which included principally Dallas, Fort Worth, and Wichita Falls. Meetings were alternated between Dallas and Fort Worth, with one meeting a year held in Wichita Falls. This proved to be a satisfactory arrangement, but the new Section was organized in the belief that membership would be better served by a unit in both Fort Worth and Dallas (future center of the North Texas Section). Members in the Wichita Falls area will be polled in the immediate future to determine whether or not they wish to remain a part of the present North Texas Section or to be affiliated with the Fort Worth group.

This new Section will include nine counties surrounding Fort Worth and at present has 151 AIME members on its

A. H. CRAWFORD

H. J. GRUY

roster. H. J. Gruy, a petroleum consultant in Fort Worth, was elected its first chairman. Other officers are: R. W. Erwin, first vice-chairman; John G. Richards, second vice-chairman; Roy T. Durst, third vice-chairman; T. M. Curtis, secretary-treasurer; R. G. Parker, section delegate and Directors R. G. Parker, G. H. Fisher, Jack Duree, George H. Gray and W. A. Shaeffer.

As was the case of the South Plains and Fort Worth Local Sections, the newly-organized Lou-Ark Section has been created from an already-existing unit. Growing out of the East Texas Section, which was organized in 1946, the Lou-Ark includes counties in Louisiana, Arkansas, and Texas which were formerly held by the East Texas Section. For a number of years, this Section has endeavored to hold two meetings a year with the Shreveport Geological Society. Interest stimulated by these meetings and by the growth of the industry in that region has resulted in the necessity for a separate Section to administer to the 80 AIME members residing in the area. Shreveport will be the focal point for the regular meetings. At the first organizational meeting in October, A. H. Crawford of the Crawford Drilling Co. was appointed chairman. Other officers are Sam Poythress, first vice-chairman; C. R. Olsen, second vice-chairman; and George C. Hollinger, secretary-treasurer.

As the first steps in the procedure to organize a Section, an organizational meeting is held to establish a temporary Section with temporary officers and to ascertain that at least 25 AIME members reside in the area to be served by the proposed Section. A petition, signed by not less than ten AIME members, and a set of bylaws, approved by the majority of available AIME members in the region, are submitted to the Petroleum Branch Secretary. The Secretary, arranging boundaries with adjacent Local Sections, then places the request for a new Section with the Branch Executive Committee. Following approval by the Committee, the petition and bylaws are presented to the AIME Board of Directors for final approval. The Section, if approved, is then a going concern.

The decision of the Board of Directors in June to decentralize administration of Local Sections, making the Petroleum Branch headquarters in Dallas the focal point of all Section business, created a question in the organization of new groups. The Branch Executive Committee was faced with the problem as to what type of local unit should be formed. After deliberation, the Committee ruled to adopt a basic policy of forming new AIME Local Sections in all areas where possible, in lieu of Sub-Sections of present Sections or new petroleum Chapters. This policy facilitates administration of Local Sections and puts all units on the basis of being legal AIME units, but to be administered by the Petroleum Branch.

Local Sections were first adopted by the AIME in 1911 when it became apparent that participation in general meetings was limited because of the widely scattered nature of the membership. Local Sections, who function alternately as hosts for annual and regional meetings, make attendance possible for a larger majority of the membership. Local Sections also provide fellowship and cooperation through regular meetings provided for the discussion of mutual interests relating to the industry.

★ ★ ★

Valuation Symposium Set for AIME Annual Meeting

A symposium on "Valuation of Oil and Gas Properties" to be sponsored by the Economics Committee of the Petroleum Branch, AIME, will be one of the highlights of the AIME Annual Meeting to be held in Los Angeles, Calif., Feb. 14-19, 1953, at the Statler Hotel.

Chairman and co-chairman for the symposium will be Everett Trostel of DeGolyer and MacNaughton, and Kenneth E. Hill of the Chase National Bank, respectively. Hill is also chairman of the Economics Committee.

The symposium will be opened at 2 p.m., Feb. 17, with brief introductory remarks by Paul Paine, consultant, of Los Angeles. Dean Sheldon will then give a paper on "Valuation of Oil Properties" which will cover the several methods of estimating oil reserves, the estimation of rate of production and selling price of oil, and the elements of cost.

Ralph E. Davis, consultant, of Houston, Tex., will give a paper on the "Valuation of Natural Gas Properties" which will include the various methods of estimating dry gas and casinghead gas reserves and gas and natural gas liquid reserves in condensate reservoirs. The paper will discuss the rate of production of gas reserves including long-term gas contracts, deliverability, and cycling. The factors of cost, such as development and operating, will be investigated, and a typical calculation of present worth of future net revenues will be shown.

The symposium will be rounded out with papers by Lyon F. Terry of the Chase National Bank on "Valuation of Oil and Natural Gas Properties for Loan Purposes" and Edwin L. Kennedy of Lehman Brothers, New York, on "Valuation in Petroleum Security Analysis." The latter paper will cover the various kinds of securities and types of companies in the petroleum industry and the essential factors in preferring one security over another.

General Chairman for Petroleum Activities at the Annual Meeting will be Howard C. Pyle, president of the Monterey Oil Co. Principal activities of interest to Petroleum Branch members will be:

Council of Section Delegates Meeting	Feb. 14
AIME Board of Directors Meeting	Feb. 15
Open Meeting, Petroleum Branch Executive Committee	Feb. 16
Annual Production Review Session	Feb. 17
Technical Session	Feb. 17
Oil and Gas Property Valuation Symposium	Feb. 17
Petroleum Branch Banquet	Feb. 17
Technical Session	Feb. 18
Technical Session	Feb. 18
AIME Annual Banquet	Feb. 18
Petroleum Field Trip	Feb. 19

★ ★ ★

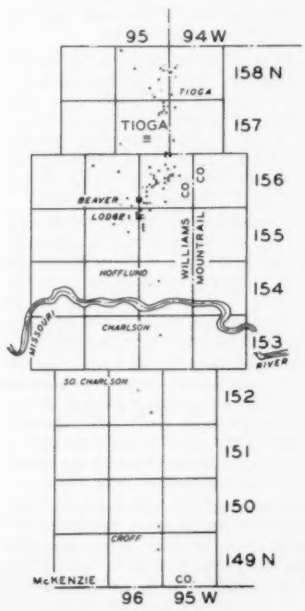
The Nesson Anticline Area Of the Williston Basin

Reported by W. B. Davis
Mid-Continent Section

At a regular meeting of the Mid-Continent Section of the AIME on Oct. 13, C. H. Danchertsen of the Amerada Petroleum Corp. discussed activities in the Nesson Anticline area of the Williston Basin.

The two principal fields found to date on the Nesson Anticline of North Dakota are the Beaver Lodge Field with 44 producing wells and the Tioga Field with 14 producing wells. The location of these fields is shown on the map. A third productive area known as the Croff Field further to the south has one small well. There have been nine dry holes drilled in this general area. The current completion rate amounts to about 15 wells per month with 20 rigs active.

The principal producing horizon is the Madison limestone found at about 8,500 ft. Production has also been tested lower at depths of 10,500 and 11,600 ft; however, it has not been developed at this time. Most of the rigs drilling in this area are 1,000 hp jackknife rigs, which can drill these 8,500 ft development wells in 40 days at a cost of about $135,000 per well. Customary procedure is to drill the surface hole, set and cement the surface pipe at 600 ft and then drill through the Madison. At this point a regular electric log, a Laterolog, a Microlog, limestone sonde and a radioactivity log are run. Seven-in. or 5½-in. casing is set through the Madison and cemented with 600 to 700 sacks. The productive interval in the Madison is perforated with four holes per ft and the well acidized with 1,000 to 2,000 gal. All but one of the producing wells completed to date have flowed on completion and usually exhibit an initial potential in excess of the 200 B/D allowable. A few wells have produced water initially.



The porosities measured on cores to date have run from 5 to 15 per cent and permeabilities measured have varied from 0 to 100 md. The initial bottom hole pressure in the Beaver Lodge Madison Pool was 3,821 psi and there has been no significant decline to date. Cumulative production from the entire area has been about 650,000 bbl. The oil was initially undersaturated, having a bubble point of 3,100 psi. The solution gas/oil ratio is about 1,200 cu ft/bbl and the formation volume factor about two.

C. H. DANCHERTSEN

A typical tank battery consists of a horizontal separator, a heater treater and several 1,000-bbl stock tanks. The principal production problem to date has been paraffin. It is necessary to run a paraffin knife an average of about twice per month in the wells. The allowable of the wells is fixed at 200 B/D per well by the North Dakota Industrial Commission. The wells are also subject to a limiting gas/oil ratio of 2,000 cu ft/bbl.

The development of Beaver Lodge and Tioga is proceeding at a rapid pace and there is little doubt but that this will constitute one of the United States' major oil fields. ★ ★ ★

Homer G. Riley Talks to Study Group On Cycling Gas Condensate Reservoirs

Homer G. Riley of Stanolind Oil and Gas Co. led a discussion at the Mid-Continent Section Study Group meeting Oct. 28 on the economics of cycling gas condensate reservoirs. The purpose of cycling gas condensate reservoirs usually is to prevent the loss of liquids from retrograde condensation and thereby to achieve a greater ultimate net operating income from the depletion of the reservoir. This additional income from the liquid hydrocarbons must pay for the additional investment necessary to install cycling facilities, in many cases increased operating costs, and the decrease in gas available for sale caused by additional fuel and shrinkage losses, if the cycling operation is to be an economic success.

The effect of several economic factors on the economics of cycling were reviewed. In order to estimate quantitatively the effect of these factors, a hypothetical gas condensate reservoir was assumed and the ultimate profit and cash position at various times from various operating methods calculated.

Two different types of reservoir fluids were considered; the first a gas relatively lean in liquid hydrocarbons and the second, a gas relatively rich in liquid hydrocarbons. For each of these two assumptions, the economics of pressure depletion and the economics of cycling were calculated with assumed constant gas prices of 4c and 12c per MCF, and assuming that the price

Continued on Page 6, Section 2

ELEMENTS OF PETROLEUM PRODUCTION—VII

Production from Gas Depletion Reservoirs

Reported by J. A. Klotz

Pacific Technology Forum

Oran A. Graybeal, superintendent of the exploitation department of the California division of the Sunray Oil Corp., presented a talk last month on production from gas depletion reservoirs as the seventh talk in the series on "Elements of Petroleum Production" that is being sponsored by the Pacific Technology Forum. Graybeal's talk was the first of four talks in which production from four different types of oil reservoirs will be discussed. The first six talks in the series discussed exploration methods, methods of determining the properties of reservoir rocks and fluids, and methods of applying these properties to determine reservoir behavior.

Graybeal began his talk with a definition of a gas depletion drive reservoir; he then described the general behavior of this type of reservoir and discussed methods for predicting pool gas/oil ratio and pool pressure as a function of production. He showed how to predict oil production rates by means of the Babson method after pool pressure has been obtained as a function of cumulative production. The talk concluded with a summary of assumptions that are necessary to predict behavior of a gas drive reservoir and with brief comment on the effect of such reservoir variables as well spacing and production rate on ultimate cumulative production.

DEFINITION OF GAS DEPLETION DRIVE RESERVOIR

A reservoir can be called a gas depletion reservoir only if all of the driving force available for driving oil into the well bore comes from compressive energy stored in oil and gas within the reservoir. Within this definition, a differentiation may be made between two types of gas drive reservoirs. In the first of these types, all of the reservoir gas is dissolved in the oil; so that all hydrocarbons in the virgin reservoir are in a single fluid phase. In the second type of reservoir, free gas is present in a gas cap as well as in solution in the oil. Although production histories of these two types of reservoir are similar, Graybeal limited his discussion to the first type, solution gas reservoirs.

Three requirements that must be met before a reservoir can be considered a gas depletion reservoir are implied in the definition. First, there can be no energy, other than the pressure energy of hydrocarbon fluid, available to drive oil into the well bore. Second, the reservoir must be closed; it must have no outlets to active aquifers or to other reservoirs. Third, gravity effects must be negligible. Only a few oil reservoirs meet all of these requirements. In California, several of the Sespe reservoirs in the coastal area, several of the Stevens reservoirs in the San Joaquin Valley, and several Miocene reservoirs in Los Angeles basin closely approach true gas depletion drive reservoirs.

BEHAVIOR OF DEPLETION DRIVE RESERVOIRS

Ideal depletion gas drive reservoirs are typified by five behavior characteristics. Whereas few actual reservoirs exhibit all of these characteristics throughout their lives many reservoirs behave as though they were true depletion drive reservoirs for part of their lives. For example, a reservoir may behave as a depletion drive reservoir until reservoir pressure drops low enough to allow a natural water drive to become active; or a reservoir may behave as a solution gas drive reservoir until a free gas cap accumulates near the top of the structure.

The first characteristic of a depletion gas drive reservoir is a gas/oil ratio that is low during the early life of the reservoir, rises to a maximum, then drops again as the field nears total depletion. As long as all parts of the reservoir remain above the bubble point pressure, the produced gas/oil ratio will be constant at the solution gas/oil ratio. The length of time that the reservoir can be produced at this GOR and the quantity of oil that can be produced depend on the difference between initial reservoir pressure and bubble point pressure and on liquid expansibility of the oil. As reservoir pressure drops below the bubble point pressure, gas separates as a second phase within the reservoir. Gas saturation and gas permeability increase, particularly at the low pressure areas around each well; oil productivity decreases, and the gas/oil ratio increases rapidly. Because of increased gas production, greatly in excess of the solution GOR, the reservoir literally runs out of gas; the pressure declines rapidly and reduces oil production by removing available pressure differential. As gas becomes depleted, the gas/oil ratio drops slowly.

The second characteristic of gas depletion drive reservoirs is this continuous and rapid pressure decline. Because the reservoir is closed and because no energy is available other than gas and oil expansion energy, reservoir pressure declines in direct proportion to the volume of fluids removed from the reservoir. The plot of reservoir pressure as a function of cumulative production is nearly a straight line with a change of slope when the reservoir passes through the bubble point.

The third characteristic of these reservoirs is declining productivity, which occurs for several reasons. As reservoir pressure declines, less energy is available to drive oil into the wells. As pressure declines below the bubble point, increased gas saturation causes lowered oil permeability so that the oil production rate is further decreased; and as gas vaporizes increased oil viscosity accentuates productivity decline.

The fourth characteristic of these reservoirs is that all wells produce at a gas/oil ratio that is independent of their position in the reservoir. Flank wells may produce at a ratio that is equal to the ratio of wells on the crest of the structure. According to the definition stated in the preceding section, gravity can have no effect in a gas drive reservoir; gas cannot migrate up structure and oil cannot drain to flank wells.

Because neither bottom nor edge water is active, the fifth characteristic of depletion drive reservoirs is low water production. The only water that can be produced is (1) interstitial water that flows into the well along with gas in an aqueous vapor phase, or (2) water contributed by expansion of the interstitial water.

PREDICTION OF PRODUCTION AND PRESSURE PERFORMANCE

Graybeal listed five methods for predicting the behavior of depletion gas drive reservoirs that are in common use. These may be separated into two classes: first, the differential equation methods and, second, the material balance methods. The material balance methods are equivalent to integration of the fundamental differential equations by several different ingenious methods. Among these are the Tarner method, the method of intersections, and the Schilthuis equation method. These methods all obtain their solutions from the basic material balance equation by graphical or by trial-and-error procedure. Because of its convenience, the Schilthuis method probably is used more often than the others; Graybeal discussed in detail methods of applying the Schilthuis equations and their limitations.

The differential equations, from which all of these methods are derived, are based on five assumptions. Several of these are implicit in the definition of a gas depletion drive reservoir and the other assumptions are necessary because only average compressibility, relative permeability, gas and oil saturations, and reservoir pressure can be used in the equations. The first of these assumptions is that the reservoir fluids are in complete equilibrium with each other at all points within the reservoir. That is, the equations assume that the oil phase within the reservoir is completely saturated but not supersaturated with gas. The next assumption is that the gas vaporization process may be described either graphically or analytically. Usually, this process can be assumed to be a differential vaporization, but many times this assumption leads to error. Engineers tend to think of gas and oil as two simple phases that are completely independent of each other. These two phases are, however, quite dependent on each other. The volume of gas that vaporizes from a barrel of oil as pressure declines depends on the composition of the gas and the oil as well as on the vaporization process. Oil shrinkage also will be different if gas vaporizes by a differential process rather than by a flash process. For the analysis of some reservoirs, the simplification of the reservoir fluids to two independent phases may lead to serious error. The final oil and gas separation in the gas trap approaches a flash separation, but this should not be confused with the first separation which takes place in the reservoir under greatly different conditions.

The third and fourth assumptions are that relative permeabilities of the reservoir to gas and oil are functions of the gas and oil saturations alone, and that these saturations are uniform throughout the reservoir at any particular time. These assumptions are necessary because the equations are not capable of handling more than one gas saturation, one oil saturation, one gas permeability, and one oil permeability. For best results, the saturation inserted in the equations should be weighted average of the gas and oil saturation that exists in the reservoir. The assumption of uniform saturation implies that all parts of the reservoir are at the same pressure; pressure draw down at each well, and pressure gradients across the field are neglected. In effect, this assumption implies that transient effects are negligible and that the reservoir is being produced at a very low rate. This assumption also implies that neither gas[2] and oil properties nor saturations change because of gravity effects within the reservoir. In high closure reservoirs, the assumption may be seriously in error. For example, the equilibrium solution gas/oil ratio may vary by as much as two-fold from top to bottom of a reservoir with a 2,000-ft closure.

The last assumption is that the reservoir volume available to hydrocarbons does not change; that is, interstitial water does not expand as reservoir pressure declines; there is no influx of edge or bottom water and the reservoir rock does not compact (porosity does not decrease) as pressure declines.

Table I — Nomenclature for Schilthuis Equations

N = stock tank oil originally in place, bbl
$\triangle N$ = cumulative stock tank oil produced, bbl
u = formation volume factor of oil and gas originally dissolved in it
u_o = original value of u
R = produced gas/oil ratio, std cu/ft bbl tank oil
R_c = cumulative gas/oil ratio, std cu ft/bbl tank oil
r = solubility of gas in oil, std cu ft/bbl tank oil
r_o = original value of r
V = gas formation volume bbl/std cu ft
β = formation volume of oil phase
β_o = original value of β
ρ_L = total liquid saturation
μ = viscosity, cp
K = permeability, md

The three Schilthuis equations decribe the state of the reservoir at any time after production has started. The three equations show the relationship of liquid saturation and gas/oil ratio (after $\triangle N$ bbl of stock tank oil have been produced) to N, the number bbl of stock tank oil originally in place and to the properties of the reservoir rock and fluid. The first equation,

$$N = \frac{\triangle N\,[u + (R_c - r_o)\,V]}{u - u_o} \quad . \quad . \quad . \quad . \quad . \quad (1)$$

is a material volume balance that equates the reservoir volume of the stock tank oil originally in place to the reservoir volume of the stock tank oil after $\triangle N$ bbl of oil and the gas associated with this oil have been produced. The second equation describes the producing gas/oil ratio for the reservoir after $\triangle N$ bbl of stock tank oil have been produced. This equation is as follows:

$$R = r + \beta/V)\,(\mu_o/\mu_g)\,(K_g/K_o) \quad . \quad . \quad . \quad . \quad (2)$$

The third equation shows the total liquid saturation:

$$\rho_L = (\beta/\beta_o)\left(1\frac{\triangle N}{N}\right)(1-\rho_W) + \rho_W \quad . \quad (3)$$

The weakest link in the Schilthuis method lies in the K_g/K_o term of Equation (2). This term can be measured on small cores in a laboratory, but these results usually cannot be applied directly to field conditions. For example, if a reservoir is composed of several layers of different permeabilities, the apparent average K_g/K_o will be higher than the averages of the K_g/K_o measurements for cores from each layer. Also if any variation of gas saturation exists within the reservoir, it will perform as though K_g/K_o is much higher than the laboratory average because the areas of high gas saturation contribute a large proportion of the total gas production. For these reasons, GOR as calculated from the second Schilthuis equation may be greatly different than the measured GOR. In the later life of a reservoir, when the relation between K_g/K_o and ρ_L can be computed over a fairly large range of $\triangle N$, an extrapolated trend for K_g/K_o can be used in the prediction of continued performance. But this device obviously is not possible in the early life of the reservoir.

The procedure used for applying the Schilthuis equations may be stated briefly as follows:

(1) Compute the oil production that will be required to bring the reservoir down to its bubble point pressure. This

computation is outside of the Schilthuis equation, which applies only below the bubble point pressure, and the volume of oil resulting from this calculation should be added to the volume resulting from the Schilthuis calculation.

(2) Assume an arbitrary pressure below the bubble point pressure and assume a trial value for $\triangle N$.

(3) Use this trial $\triangle N$ and appropriate liquid properties in Equation (3) to determine p_L.

(4) Determine K_o/K_o from its relation to p_L as determined from laboratory data or later from pool performance.

(5) Use this K_o/K_o and the appropriate fluid properties in Equation (2) to calculation the produced GOR.

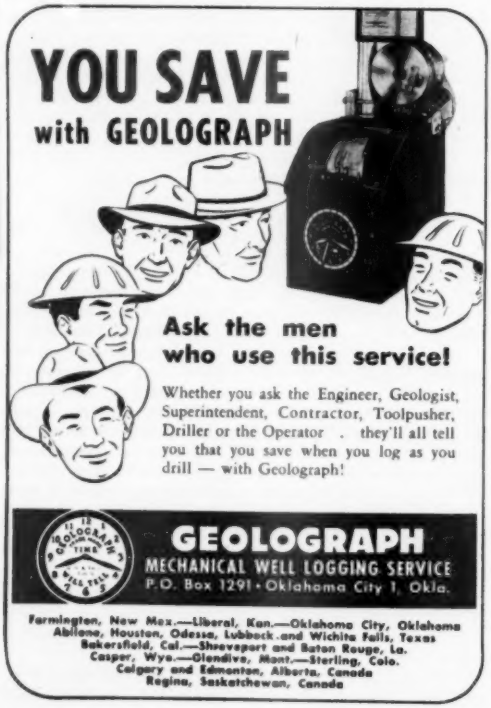
(6) Compute the average GOR for the period that corresponds to the production of $\triangle N$ bbl of stock tank oil.

(7) From this GOR, calculate total gas production and accumulate this gas production to determine R_s.

(8) Insert this R_s and appropriate values for u, u_w, r_w, and V in Equation (1); calculate N.

(9) If this value of N is not satisfactory, assume a second trial value of $\triangle N$ and repeat the calculation as many times as necessary to obtain a satisfactory N. After experience in these calculations has been obtained two or three trials are usually sufficient to obtain a satisfactory agreement between $\triangle N$ and N.

(10) After this agreement has been obtained for the first assumed pressure, assume a second pressure below the first and repeat the calculation. As many pressure steps as necessary may be made to plot gas/oil ratio and pressure as a function of the number of barrels of tank oil produced.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After pressure and GOR have been determined as a function of oil production, time may be introduced in order to determine production rates by either the Babson method or by extrapolation of the productivity indices of the wells in the reservoir. The Babson method uses an equation that relates productivity index to gas and oil permeabilities and to the well draw down. The results obtained with this equation are, similar to the Schilthuis equation, dependent upon accurate K_o/K_o data. The Babson equation and the procedure for using it are as follows:

$$I/I_i = \frac{1}{P_e - P_w}\left(\frac{\mu_o \beta}{K_o/K}\right)_i \int_{P_w}^{P_e} \left(\frac{K_o/K}{\mu_o \beta}\right) dP \quad . \quad (4)$$

I = productivity index in bbl/psi-day
I_i = initial productivity index
P = pressure in formation, psi
P_e = pressure at drainage radius
P_w = pressure at well bore

To determine I/I_i after $\triangle N$ barrels of oil have been produced, calculate $(K_o/K)/(\beta\mu_o)$ as a function of pressure for the GOR shown by the Schilthuis equations to correspond to the $\triangle N$ in question. Evaluate the Babson integral graphically between the pressure limits of P_w and P_e. Insert this result into the Babson equation to determine productivity index ratio.

Graybeal concluded his talk with a summary of uncertainties that arise in the calculation and prediction of the behavior of depletion gas drive reservoirs. Lack of equilibrium between gas and oil phases, for example, may have a large effect on the calculated reservoir behavior. Engineers usually assume that if reservoir fluids are not in equilibrium they are so close to equilibrium that the difference can be neglected, but they do not know just how important this difference may be. A second error may arise because accurate reservoir pressure data are not available. These data require either long-term build-up curves or accurate methods of extrapolating short build-up curves; often neither of these is available. This error is particularly troublesome in low permeability reservoirs.

Relative permeability curves are always measured on core samples that represent a very small portion of the reservoir. Curves from several core samples are difficult to average and this average may be far different from the curve that should be used in the reservoir for behavior calculations.

The methods of determining reservoir behavior described here apply to a reservoir with no initial gas cap. Such a gas cap may exist, however, and if it is undetected, reservoir performance predictions may be far in error.

Two other variables that may influence reservoir behavior, but are not explicitly considered in the calculation methods described by Graybeal, are well spacing and production rate. As mentioned earlier, production rates are usually assumed to be so small that pressures are uniform throughout the field. Large drawdowns certainly change field performance, but no simple and direct method is known, at present, for computing this effect. Well spacing also does not enter these simplified prediction calculations, and probably the ultimate production that can be achieved from a true solution gas drive reservoir is independent of spacing if economics and time can be ignored. If other mechanisms, such as water drive or gravity effects, are present, ultimate production may depend more directly upon well spacing. Well spacing and producing rates are largely determined by economic considerations beyond the range of these reservoir behavior equations, and must be evaluated carefully in each oil reservoir. ★ ★ ★

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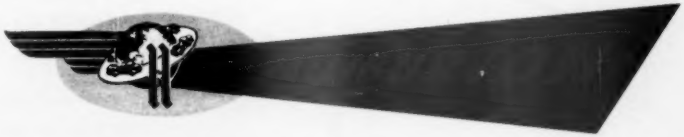

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IMPROVED TECHNIQUES DEVELOPED FOR ACIDIZING GAS PRODUCING AND INJECTION WELLS

W. H. JUSTICE AND **JENS P. NIELSEN,** LA GLORIA CORP., CORPUS CHRISTI, TEX., MEMBERS AIME

ABSTRACT

This paper describes an improved acidizing technique which has been applied in acidizing gas wells in the La Gloria Field. Wells acidized in this manner exhibited a much greater increase in deliverability than wells acidized in the conventional manner. The acid is injected into the well in small slugs separated by a small volume of high pressure gas. The acid and gas are displaced from the tubing by high pressure gas to reduce the hydrostatic head on the well when the acid is recovered from the well. The well is opened for production as soon as the acid and gas are displaced. This procedure permits a very rapid recovery of the acid which results in large increases in the deliverability of the gas wells.

It has been found advantageous in the acidization of gas injection wells to inject the high pressure gas directly after the acid without backflowing the acid out of the well. This practice has made it possible to inject the gas in the injection wells of this field with a much lower pressure differential. This reduces the horsepower required to inject the gas and also decreases the number of injection wells required per reservoir.

INTRODUCTION

The results obtained by acidizing gas wells in the La Gloria Field have varied considerably in the past. For this reason, a planned study of the acidizing procedure was undertaken in order to obtain more consistent results.

The Frio Sands of the La Gloria Field are rather permeable and it was not necessary to acidize many of the wells when they were originally completed. At the completion of an eight-year cycling program in several of the gas reservoirs, it became necessary to recomplete many wells in other reservoirs. It was found that the open flow potential of the wells recompleted in different sands was not as large as wells that were originally completed in that reservoir.

A study of the drilling records of several of these wells indicated that the sands had originally been subjected to considerable hydrostatic drilling fluid overload while the well was being drilled to the deeper sands of the field. It is indicated that during this eight-year period, the drilling mud and water that were lost into the formation when the well was being drilled had formed a relatively impermeable zone around the well bore. This impermeable zone around the well bore made it very difficult to obtain high deliverability wells when the original wells are recompleted in other zones.

Muskat[1] has shown that in uniformly permeable and porous formations a zone of partial plugging one ft in radius around the well would drastically decrease the productivity of the well. The analysis for this problem shows that the production capacity of a well is very sensitive to the value of the permeability of the zone immediately surrounding the well bore. This is to be expected in view of the highly localized character of the pressure drop in a radial flow system about the well center. The reduction of the deliverability is not proportional to the thickness of the mud-affected zone as the major portion of the reduction in deliverability is caused by the

[1]Reference given at end of paper.

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plugging of the area immediately adjacent to the well bore. Any additional increase in the thickness of the mud-affected zone causes successively smaller reductions in the well deliverability.

The major portion of the increase in production capacity from an acid treatment is due to the restoration of the permeability of the mud-affected zone to that of the main reservoir. Any increase in the permeability of the mud-affected zone or of the next few feet of the reservoir above the permeability of the rest of the reservoir, does not appreciably increase the deliverability of the well. For example, if the mud-affected zone has a radius of one ft and has a permeability of 10 per cent of permeability of the main reservoir, and this zone is restored by acid treatment so that it has the permeability of the main reservoir, the production capacity is increased 180 per cent. (See Fig. 1.) Whereas, if the permeability of this one ft zone is increased to 400 per cent more than the original reservoir permeability, the productive capacity of the well would be only 14 per cent more than the productive capacity of the well with the one ft radius zone having the same permeability as the remainder of the reservoir. (See Fig. 2.)

The object of our acidizing program was the removal of the mud and extraneous material, introduced during the drilling operation, from the well bore and the region closely adjacent to the well bore so that the original permeability of the formation could function. The need for removal of the mud and water introduced into the area closely adjacent to the well bore was more important in the case of the wells that were being worked over eight years after they were originally completed. This was evidenced by the lower open flow potential of these wells, probably due to the mud and water that was introduced into the formation having been subjected to the formation temperature for sufficient time to set up and cause the maximum reduction in the permeability of this portion of the formation.

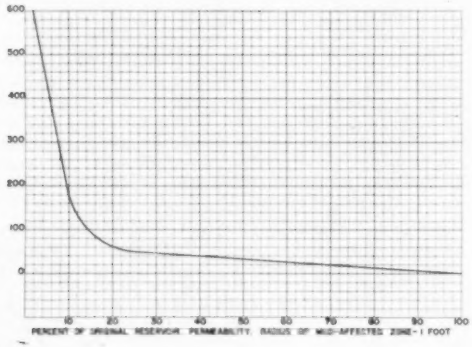

FIG. 1 — INCREASE IN THE PRODUCTION CAPACITY OF A RADIAL FLOW SYSTEM DUE TO ACID TREATMENT IF THE ACID-AFFECTED ZONE WITH A RADIUS OF ONE FT WAS PARTIALLY PLUGGED BY MUD WHICH HAD LOWERED THE PERMEABILITY BELOW THE REST OF THE RESERVOIR AND THE ACID TREATMENT RESTORES THIS ZONE SO THAT IT HAS THE PERMEABILITY OF THE ORIGINAL RESERVOIR.

It was found that acidizing these wells by conventional methods did not result in the desired increase in deliverability. The purpose of this paper is to describe the acidizing technique that was developed which has resulted in a much greater increase in deliverability than the conventional acidizing procedure.

DESCRIPTION OF THE ACIDIZATION OF A TYPICAL GAS PRODUCING WELL

This gas well was recompleted into the Frio Sand "A" after having been produced from another sand for eight years. The pertinent reservoir data for Sand "A" is shown in Table I. The well was equipped with 2½-in. tubing set on a Baker production packer in 7-in. casing. The well was jet perforated from 6,714-36 ft with six shots per ft.

On a 10-hour production test the well would only flow at a rate of 3.8 MMcf/D with a maximum flowing pressure of 800 psig. The well would not flow into the gas gathering system which is maintained at a pressure of 1,750 psig. The other wells completed in Sand "A" after acidizing were capable of producing at a rate of 8 MMcf/D into the gas gathering system. It was decided to acidize this well in an attempt to increase the productivity.

It was estimated that the total capacity of the tubing and casing below the packer to the center of the perforations was 40.5 bbl. It was also estimated that the hydrostatic head of a 6,725 ft solid column of acid would be 3,130 psig or 380 lb greater than the 2,750 psig reservoir pressure. The well, therefore, would not be capable of backflowing the acid and it would be necessary to swab the acid back if the well were acidized in the conventional manner. It was decided to inject the acid in 10 bbl slugs separated by a small volume of high pressure gas so that the well would not have to produce against the full hydrostatic head of the acid column. Each 10 bbl slug of acid would be displaced from the tubing by the expansion of the high pressure gas before the next 10 bbl slug of acid entered the tubing. This procedure would permit the rapid recovery of acid without swabbing, and would prevent the separation and deposition of mud particles around the well bore from the partially spent acid.

The acid truck and pump line were connected and tested for leaks at a pressure of 5,500 psig. The mud acid was pumped into the tubing at a rate of 2.5 bbl per minute. The initial pump pressure was 2,370 psig and the pressure decreased to 1,875 psig after 10 bbl of acid had been pumped into the tubing. In this size tubing, 10 bbl is equivalent to a column of liquid 1,700 ft long. High pressure gas was then injected into the tubing at a high rate for approximately five minutes. This cycle was repeated. After pumping a total of approximately 34 bbl of acid, the pressure built up to 2,900 psig. This indicated that the initial acid had reached the formation. A slight break in the pressure occurred and the pumping pressure decreased to 2,600 psig.

The pumping of the acid in 10 bbl slugs separated by a slug of high pressure gas was continued until a total of 96 bbl of acid had been injected into the well. The acid and gas were then rapidly displaced into the formation from the tubing with high pressure gas. The acid was then immediately backflowed from the well. Since the acid was separated into the

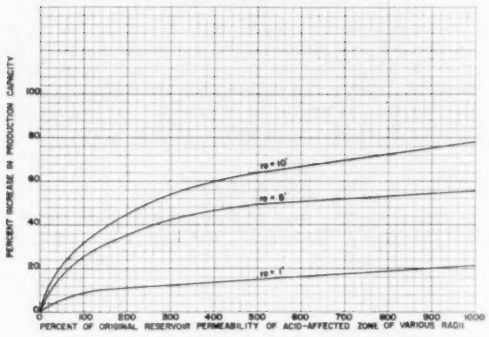

FIG. 2 — INCREASE IN THE PRODUCTION CAPACITY OF A RADIAL FLOW SYSTEM DUE TO ACID TREATMENT IF THE INITIAL PERMEABILITY IS EVERYWHERE UNIFORM AND THE PERMEABILITY OF THE ACID-AFFECTED ZONE OF VARIOUS RADII IS INCREASED ABOVE THE PERMEABILITY OF THE ORIGINAL RESERVOIR.

small slugs by the high pressure gas, each slug of acid was ejected from the tubing before the next slug of acid entered the tubing. This permitted the well quickly to clean itself of the acid without being swabbed. As the well cleaned up, the flowing pressure rapidly increased and at the end of eight hours the well was flowing at a rate of approximately 11 MMcf/D with a tubing pressure of 1,850 psig. The open flow potential of the well was estimated at 48 MMcf/D. The well is now capable of flowing into the gas gathering system at a rate in excess of the 11 MMcf/D.

DESCRIPTION OF THE ACIDIZATION OF A TYPICAL GAS INJECTION WELL

It has been found advantageous to acidize the injection wells used in the cycling program of the La Gloria Field in order to reduce the horsepower required to inject the gas and to reduce the number of wells required per reservoir. We had been acidizing these wells in the conventional manner and had obtained satisfactory increases in size of the injection wells. The end-to-end sweep plan of cycling one of the reservoirs recently included in the cycling program called for the injection of gas slightly below the original gas-water contact. The well selected for this injection was recompleted and considerable salt water was produced at a high rate in an effort to clean the well. Gas was then injected into the well, but only 3 MMcf/D could be injected at an injection pressure of 3,300 psig.

The well was then acidized with 4,000 gal of acid. (See Table I for reservoir data on Sand "B".) The acid was displaced from the tubing with kerosene in an effort to increase the speed with which the acid could be recovered from the well. The acid was recovered and enough salt water was produced to clean the well. The acidization caused no increase in the volume of gas that could be injected into the well at the same injection pressure.

The decision was then made to re-acidize the well in a different manner. Two hundred gallons of wash acid were pumped into the well, followed by 3,000 gal of mud acid and 800 gal of wash acid. The acid was displaced from the tubing with the injection gas without backflowing the acid out of the well. The gas injection rate was very low for the first two hours. At the end of two hours the rate of injection increased sharply, and at the end of 12 hours the injection rate of 2,850 psig was 19 MMcf/D. The acid treatment resulted in a sixfold increase in the injection rate of the well.

In order to increase the injection rate of a well completed in a different reservoir considerably above the gas-water contact, it was decided to use the same acidizing procedure that had been used on the injection well completed below the gas-water contact. (The reservoir data for Sand "C" is shown on Table I.) Four thousand gallons of mud acid were pumped into the well. The acid was displaced from the tubing with the injection gas without backflowing the acid from the well. The gas injection rate was very low for the first two hours, but at the end of this period there was a sharp increase. At the end of 12 hours the injection rate at 2,700 psig was 36 MMcf/D, whereas, the injection rate before the well was acidized was only 9 MMcf/D with an injection pressure of 2,850 psig. The acid treatment resulted in a fourfold increase in the gas injection rate of the well with a 150 psig reduction in injection pressure.

CONCLUSIONS

Gas wells in which the permeability of the formation near the well bore has been drastically reduced by mud are the most difficult to acidize by conventional methods. It has been found that the injection of the acid in small slugs separated by a small volume of high pressure gas, reduces the hydrostatic head on the well when the acid is recovered. Each slug of acid is displaced from the tubing by the expansion of the high pressure gas before the next slug of acid enters the tubing. This procedure permits very rapid recovery of the acid which evidently restores the original formation permeability of the mud-affected zone and results in large increases in the deliverability of the gas wells. Wells that are so tight that

Table I — Reservoir Data for Various Frio Sands, La Gloria Field, Jim Wells and Brooks Counties, Texas

	Sand "A"	Sand "B"	Sand "C"
Producing Horizon	Frio	Frio	Frio
Average Porosity	22.8%	17.2%	20.8%
Average Permeability	521 md	100 md	220 md
Depth of Perforations	6,714-36'	5,724-50'	5,984-6,048'
Average Pressure, psia	2,750	2,650	2,970
Reservoir Temperature, °F	196	178	188

it would be necessary to recover the acid by swabbing can be quickly and safely acidized by this procedure without swabbing. This acidizing procedure should make it profitable to acidize many wells that are now considered too tight to acidize by the conventional method. Where high pressure gas is not available at the well, it should be profitable to use a portable gas compressor to compress and inject gas or air along with the acid, as described in this paper.

It was found to be more effective to displace the acid in a gas injection well with the injection gas without backflowing the acid out of the well. This procedure resulted in a fivefold increase in the amount of gas that could be injected into the well.

ACKNOWLEDGMENT

The authors wish to express their appreciation to the La Gloria Corp. for permission to prepare and publish this paper. We also express our appreciation to L. G. Cable, R. E. Denmead, J. Eskew and C. L. Wheless for their assistance in obtaining the data reported in this paper.

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SURFACE AREA MEASUREMENTS ON SEDIMENTARY ROCKS

C. S. BROOKS AND W. R. PURCELL, SHELL OIL CO., HOUSTON, TEX., MEMBERS AIME

ABSTRACT

The internal surfaces of rocks which are in contact with interstitial fluids are known to influence in some degree the recovery of hydrocarbons from pay zones. Despite the admitted importance of the influence of solid surfaces on hydrocarbon recovery, little information is available concerning the extent of surface of reservoir rocks. In this paper a description is given of the apparatus and procedure employed in the determination of the surface areas of sedimentary rocks, and values are reported for a variety of sandstone and limestone cores. In addition, consideration is given to the Kozeny equation, which relates surface area to porosity and permeability. A comparison is made between the surface areas as calculated from this equation and the geometrical areas of a series of packs of spherical glass beads. Also, for a group of sandstone cores, Kozeny areas are compared with surface areas as determined by the gas adsorption method employed in this investigation.

INTRODUCTION

It has long been recognized that many processes which are of importance to hydrocarbon production are controlled in some degree by the extent of the surface of the reservoir rock through which the hydrocarbons move. For example, the recovery efficiency that is obtained in a given reservoir is certainly determined in part by the action of interfacial forces between the reservoir fluids and rock, and this action is influenced in turn by the extent of solid surface. Despite the admitted importance of surface effects to problems of petroleum recovery, little information is available concerning the extent of surface of reservoir rocks.* It is the purpose of this paper to describe an apparatus which has been employed for the measurement of the surface areas of rock samples and to present the values which have been obtained for a variety of sandstone and limestone cores. In addition, the relationship of surface area to permeability and porosity, as given by the Kozeny equation, will be discussed.

METHOD OF MEASURING SURFACE AREA

The method of determining surface areas as employed in this work has previously found wide use in studies of porous solids such as catalysts. The method involves the measurement of the amount of physical adsorption of an inert gas, such as nitrogen or argon, on the bare surface of the solid at reduced pressure and constant temperature near the normal liquefaction temperature of the gas. With the aid of the theory of isothermal adsorption as developed by Brunauer, Emmett, and Teller,[1] it is possible to ascertain the amount of gas (and hence the number of molecules) which is required to cover the solid surface with a single layer of molecules. From a knowledge of the covering area per molecule the total surface area of the solid can be computed.

Since the Brunauer, Emmett, Teller (BET) theory has been adequately discussed elsewhere,[2] it will suffice here merely to present their final equation as ordinarily employed for surface-area calculations. This equation relates the volume of gas, V, which is adsorbed at pressure, P, to the liquefaction pressure, P_o, of the gas, and to the volume of gas, V_m, that is required to form a monomolecular layer:

$$\frac{P}{V(P_o - P)} = \frac{1}{V_m C} + \frac{(C-1)P}{V_m C P_o} \quad . \quad . \quad . \quad . \quad (1)$$

In this equation C is a quantity which is related to the heats of adsorption and liquefaction of the gas; for a particular solid-gas system at constant temperature, C is considered to have a constant value.

The basic adsorption data can be presented in the form of Equation (1) by plotting the quantity $P/V(P_o - P)$ as a func-

[1] References given at end of paper.

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*A recent paper by Kulp and Carr [*J. Geol.*, 60, 148 (1952)] reports surface areas of deep-sea sediments. Their values are in general much higher than those reported here for reservoir rocks probably because of the high clay and silt content of the sediments.

tion of the relative pressure, P/P_o. If the adsorption follows the BET equation (and this is generally found to be the case in the range of relative pressures from 0.05 to 0.35) then this plot yields a straight line with slope $(C-1)/V_mC$ and intercept $1/V_mC$. Thus the reciprocal of the sum of the slope and intercept of the line gives V_m.

It is customary to report the volume of gas adsorbed, V, in cubic centimeters at standard conditions of 0°C and one atmosphere pressure and, hence, V_m is referred to the same conditions. If ρ is the density of the gas at these standard conditions, in grams per cubic centimeter, then the number of molecules, n, in the volume, V_m, is given by:

$$n = \frac{V_m \rho N}{M} \quad \ldots\ldots\ldots\ldots \quad (2)$$

where N is Avogadro's number and M is the molecular weight of the gas. The total surface area, S, is:

$$S = n\sigma = \left(\frac{V_m \rho N}{M}\right)\sigma \quad \ldots\ldots\ldots \quad (3)$$

where σ is the effective area covered by each molecule.

The generally accepted value of σ for nitrogen is 15.4 A^2 and for argon 13.6 A^2, and these values were employed in this work. For a detailed discussion of the methods of obtaining the covering areas of molecules adsorbed on solid surfaces, the reader is referred to a recent article by H. K. Livingston.[2]

APPARATUS AND PROCEDURE

The requisite data for determining the surface area of a porous solid by the BET method are the volumes of gas adsorbed, V, at various pressures, P. The apparatus employed in this work for the determination of these quantities is shown in Fig. 1.

This apparatus and the procedure employed are similar in most respects to those given by Barr, Anhorn, and Joyner,[4] but the following modifications are worthy of note:

1. The gas burets and manometer are housed in an air thermostat wherein the temperature is maintained at 31°C ±0.1°. The mercury levels are observed through a Thermopane window which forms the front wall of the cabinet.

2. The pressure is measured to ±0.1 mm by means of a cathetometer. The zero reference level in one leg of the manometer is maintained at a fixed position with the aid of a "magic-eye" indicating circuit.

3. The sample tube used in this work is considerably different in design than those customarily employed in surface-area determinations. In the study of materials of high surface area, such as catalysts, the surface created by moderate grinding is a negligible portion of the total, and hence the material can be used in powdered form. For materials such as rocks, which are found to have relatively low surface areas, there exists the possibility of introducing a measurable surface by grinding. It was deemed desirable, therefore, to study the rock samples in single large pieces rather than as a powder. Accordingly, the sample tube (Fig. 2) was designed to admit a specimen up to 1 in. in diameter by 2 in. long. To obtain the highest possible accuracy in the adsorption measurements it is necessary to keep the free gas space in the sample holder to a minimum. This is accomplished through the use of a pyrex hypodermic syringe, of internal diameter just slightly greater than 1 in., connected at one end to a capillary tube to which is affixed a stopcock and ground glass joint. The piece to be tested is drilled to 1 in. O.D. from a larger rock sample. As long a piece as possible is used, up to 2 in. The space above the sample in the tube is completely filled by the plunger of the syringe so that the only void space remaining in the sample holder, aside from that in the pores of the rock, is the very small annular ring between the sample and the wall of the syringe. A vacuum seal is effected by lubricating the upper portion of the syringe plunger with vacuum grease. The stopcock and glass-joint arrangement, as shown in Fig. 2, enables the sample to be heated and degassed before being attached to the measuring manifold. This permits the preparation of one sample at the same time that measurements are being made on another sample.

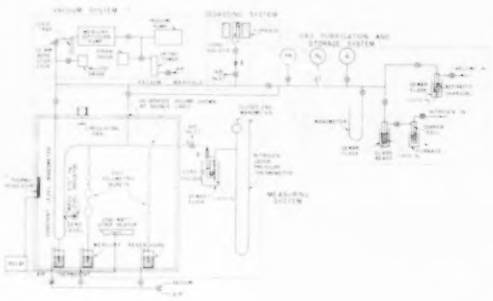

FIG. 1 — ADSORPTION APPARATUS.

4. In the procedure for surface area measurement as given in Reference (4), the gas in the sample tube and in the line connecting the tube to the measuring manifold is treated as though it were all at the temperature of the liquid nitrogen bath. This procedure is satisfactory for samples of high surface area, especially if the volume of the gas between the liquid nitrogen level and stopcock 2, Fig. 1, is small. This latter condition is often achieved by sealing the sample tube directly to the manifold by means of capillary tubing. In the apparatus here described the volume of gas between the liquid nitrogen level and the measuring manifold is somewhat greater than usual because of the addition of a ground glass joint and stopcock. For this reason, and because the surface areas to be measured are relatively small, it was found necessary in achieving the desired accuracy to treat our system as though it were divided into three zones. Zone A includes the gas bounded by the zero level of the manometer, stopcocks 1 and 2 (Fig. 1), and by the mercury levels in the two burets. Although stopcocks 1 and 2 are outside the air bath, they are placed as close as possible to it in order that all the gas of zone A can be treated as though it were at the constant temperature of the air bath. Zone C includes the gas which is below the liquid nitrogen level of the bath surrounding the sample tube; this volume of gas, which is at the fixed temperature of the boiling nitrogen,* is kept

*Variations in atmospheric pressure which may occur during the test are not sufficiently large to alter appreciably the boiling point of the nitrogen.

constant by periodically replacing the nitrogen that evaporates so as to maintain an essentially stationary liquid level in the bath. Zone *B* contains a small amount of gas (between stopcock 2 and the liquid nitrogen level) which varies in temperature from that of the air bath on the one side to that of boiling nitrogen on the other.

The volumes of gas contained within the three zones are determined prior to the adsorption measurements in the following manner: With the plunger of the sample holder removed, a melted wax, such as Apiezon *W*, is poured into the holder until the holder and the adjoining capillary U-tube are filled with wax up to the level at which the liquid nitrogen is to be maintained. This serves, in effect, to reduce the gas volume of zone *C* to zero. After the wax has solidified, the sample holder is attached to the measuring manifold. For these calibration tests the liquid nitrogen bath is omitted and the sample holder and adjoining tubing are at room temperature. The entire system is evacuated to a pressure of 10^{-5} mm of mercury. Helium is then admitted to zone *A* (stopcock 2 closed) and the volume of this zone, V_A, determined from pressure readings made at various settings of the mercury levels in the two burets.* Stopcock 2 is then opened, admitting gas to the previously evacuated tubing which connects the buret system to the wax-filled sample holder. Pressure readings are again made at different settings of the burets from which the volume of zone *B*, V_B, can be computed. The wax is then removed from the sample holder by heating and the tube is cleaned with a wax solvent. The core sample to be tested is placed in the sample holder which in turn is placed in the well of an electric furnace and attached to the vacuum manifold. The sample is heated and simultaneously evacuated to remove gas from the pores and from the surface of the rock. The sample tube is then closed at the stopcock, removed from the degassing furnace, and attached to the manifold of the measuring system. The volume of the gas below the reference mark of the sample holder (zone *C*) is then determined by helium expansion as in the aforementioned determination of the volume of zone *B*. Once determined for a given sample tube and adapter, V_B is constant, but V_C must be determined each time a new core sample is introduced.

To determine the average temperature of zone *B* which prevails during the adsorption measurements, the sample tube is immersed to the reference mark in the liquid nitrogen bath. The helium expansion measurements are again repeated. As before, the measuring manifold (zone *A*) is filled with gas to an initial pressure, P_1, of about 50 mm of mercury with the mercury levels at the lowest reference marks in the two burets. The gas volume is equal to the previously determined value of V_A. The gas is then expanded into the sample holder to a pressure P_2. The quantity (Z_BT_B) is calculated from the equation:

$$Z_BT_B = \frac{P_2V_BT_AT_CZ_C}{[(P_1-P_2)V_AZ_AT_C + P_2(\triangle V_AT_CZ_C - V_CT_A)]} \quad (4)$$

where V_B and V_C are the previously determined values** of the volumes of zones *B* and *C*, respectively; T_A and T_C are the known absolute temperatures of the air bath and of the liquid nitrogen bath; and Z_B and Z_C are the compressibility factors for helium corresponding to the pressure and temperature of zones *B* and *C*. The compressibility factor for zone *A* is considered to be unity. Duplicate determinations of (Z_BT_B) are made by varying P_2 through the additions of known amounts of mercury, $\triangle V_A$, to the burets of the measuring system. The average temperature of zone *B* can then be determined from plots of (ZT) *vs* T which are compiled, for various helium pressures, from compressibility data obtained in the literature.[5]

Although the determination of T_B is rather time-consuming, it need be made only once for a given apparatus, for it has been found that this temperature does not depend in any large degree on the gas volumes of zones *A* and *C*, nor on the gas pressure. By accounting for this intermediate temperature, it is possible to achieve sufficient accuracy in the adsorption data that surface areas as low as 0.1 square meter per gram can be reliably measured without recourse to the more exacting procedures of Wooten and Brown[6] or Beebe, Beckwith, and Honig[7] which have been designed specifically for small areas. To demonstrate the marked influence on the resultant surface area value of the temperature of zone B used in the calculations, we cite the example of nitrogen adsorption on a sandstone sample weighing 16 grams. When the gas in zone *B* was assumed to be at the temperature of the liquid nitrogen bath, the calculated surface area was 0.53 square meter per gram. On the other hand, when the gas in zone B was

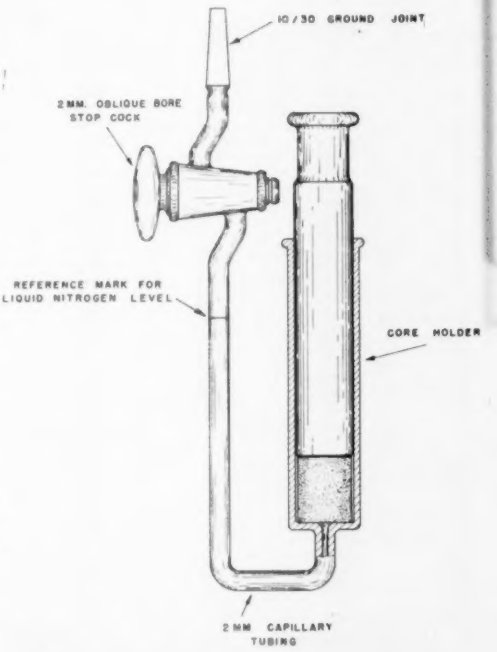
10/30 GROUND JOINT
2 MM. OBLIQUE BORE STOP COCK
REFERENCE MARK FOR LIQUID NITROGEN LEVEL
CORE HOLDER
2 MM CAPILLARY TUBING

FIG. 2 -- SAMPLE TUBE.

*For helium at or near 25°C and less than one atmosphere pressure, deviations from the ideal gas laws can be neglected since the compressibility factor differs from unity by less than 0.01 per cent.

**Although values for V_B and V_C were determined at room temperature, these same values may be used at temperatures down to that of liquid nitrogen, since calculations show that there is a negligible change in volume of the glass containers over this temperature range.

taken to be at 286°K, as found by the above-described procedure for the particular sample tube employed, the computed surface area was 0.71 square meter per gram. Thus, an error of about 25 per cent would have been made had not the temperature of zone *B* been determined.

The argon used in this work was obtained in hermetically sealed glass containers and was reported by the supplier to be spectroscopically pure. The nitrogen was purified by passing cylinder gas first over hot copper foil to remove oxygen and then through a cold trap to remove water vapor and other condensable materials. Mass spectrographic analyses of the gas before and after purification showed 98.05 mole per cent and 99.24 mole per cent nitrogen, respectively. The helium was obtained by passing "high-purity grade" tank gas over activated charcoal which was held at the temperature of liquid nitrogen.

All the core samples were prepared for the surface area measurements by extracting with a naphtha solvent (106°C B.P.), drying in an oven at 110°C and degassing for 15 hours at 110°C and 10^{-5} mm of mercury pressure. The above degassing procedure was adopted as standard sample preparation after it was demonstrated that in the case of the limestone and sandstone cores essentially constant surface area and constant weight were attained after evacuation for 15 hours at 110°C. The sample tube described above permits the weight loss of the sample to be determined after degassing, without exposure of the sample to the atmosphere, by weighing the entire sample tube and adapter assembly. The samples ranged in weight from 15 to 60 grams. An effort was made to obtain as large a sample as possible, within the limits of size set by the dimensions of the sample tube, although it was found that consistent data were obtained provided the sample was sufficiently large to give a total adsorption of one cu cm or more at the completion of the mono-layer.

In general, about six or seven adsorption points were determined for each sample in the range of relative pressures from 0.05 to 0.35. Equilibrium conditions were usually established within 30 to 60 minutes at any given pressure within this range.

EXPERIMENTAL RESULTS

The above-described method of determining surface areas by low temperature gas adsorption has been applied to numerous samples of both sandstones and limestones. The results of these measurements are given in Table I. In column four the surface areas are expressed in square meters per gram, and it will be observed that the sandstones, for the most part, have surface areas within the range of 0.5 to 6 square meters per gram, whereas the limestones have surface areas from 0.05 to 0.5 square meter per gram. When the surface areas are referred to unit pore volume, however, as in column 5, a wider variation is encountered, with the values ranging from about

Table I-A — Surface Areas of Limestones

Sample No.	Fractional Porosity, *f*	Permeability, *K* (md)	Surface Area (sq. meters per gram)	Surface Area (sq. meters per cc. pore vol.)	Surface Area (sq. meters per cc. bulk vol.)	Sample Description
			Trenton Formation — Ordovician Age			
1	0.0102	0.34	0.38	99	1.01	dn., dk., gray, w/pyrite incl.
2	0.0136	0.03	0.13	25	0.35	hard, dk. gray, w/irr. blk. pln. and incl.
3	0.0805	0.03	0.26	8.0	0.65	gray and tan, w/dk. pln. and incl.
4	0.121	29.1	0.09	1.8	0.21	tan, visible porosity
5	0.0479	0.51	0.16	8.6	0.41	tan, w/blk. irr. plns.
6	0.0465	3.37	0.11	6.1	0.29	gray and tan, w/sec. cryst.
7	0.0378	0.79	0.12	8.2	0.31	gray and brown, fossil.
8	0.0640	0.31	0.14	5.5	0.36	lt. and dk. gray, sec. cryst.
9	0.0294	0.03	0.16	14	0.42	hard, dk. and lt. gray
10	0.0370	1.50	0.21	15	0.55	gray and tan, fossil., w/irr. sh. pln.
11	0.0432	0.04	0.17	10	0.44	gray and tan, fossil., w/irr. sh. pln.
12	0.0146	0.05	0.07	13	0.19	gray and tan, sec. cryst.
13	0.0197	0.05	0.36	49	0.95	hard, dk. gray, w/irr. blk. pln. and incl.
14	0.0085	1.56	0.17	54	0.46	gray and tan, w/dk. pln. and incl.
15	0.0080	3.87	0.23	77	0.62	gray, w/blk. incl.
16	0.0109	0.32	0.06	14	0.15	hard, fossil., w/dk. irr. incl.
17	0.0606	2.08	0.14	5.9	0.36	gray, fossil., w/sec. cryst.
18	0.0360	0.04	0.17	12	0.44	tan, w/irr. frac. filled w/sh.
19	0.0461	0.14	0.12	6.7	0.31	gray and tan, fossil., w/weathered faces.
20	0.0242	0.16	0.18	20	0.48	gray and tan, w/irr. incl.
21	0.040	*	0.13	8.4	0.35	dk. and lt. gray fossil., w/dk. sh. incl.
			Caddo Formation — Pennsylvanian Age			
22	0.036	*	0.33	24	0.86	dn., w/carb. incl.
23	0.039	*	0.25	17	0.65	dn., w/sh. incl., slightly vug.
24	0.028	*	0.20	19	0.53	dn., w/carb. incl.
25	0.029	*	0.67	62	1.76	dn., carb., cryst.
26	0.023	*	0.51	59	1.35	carb., cryst.
27	0.042	*	0.01	0.6	0.03	dn., carb.
28	0.042	*	0.14	9.9	0.42	dn., carb., fossil.
29	0.035	*	0.11	8.2	0.29	dn., carb., fossil.
30	0.030	*	0.15	13	0.39	carb., cryst.
31	0.074	*	0.14	4.8	0.35	carb., cryst., slightly vug.
32	0.114	12	0.32	6.9	0.79	cryst., vug., carb.

* — permeability less than 0.1 md
blk. — black
carb. — carbonate (or carbonaceous)
crs. — coarse
cryst. — crystallization (or crystalline)
dk. — dark
dn. — dense
fossil. — fossiliferous
frac. — fractures
grn. — grained
incl. — inclusions
irr. — irregular
lt. — light
pln. — planes
sec. — secondary
sh. — shale
shly. — shaley
vug. — vugular

1 to 100 square meters per cubic centimeter of pore volume for both limestones and sandstones. For a given pore volume, therefore, the limestones present surface areas of the same order of magnitude as the sandstones. The lower areas per gram and per unit bulk volume (column 6) for the limestones can possibly be attributed to the fact that their porosities are in general much lower than those of the sandstones tested.

In Table II, examples are given of the reproducibility of surface-area measurements as indicated by the values obtained in duplicate determinations. It will be seen that the precision increases somewhat with increasing surface area, but is sufficiently good at about 0.1 square meter per gram so that areas of this order of magnitude can be reproduced to within 5 per cent to 10 per cent. For areas of from 1 to 10 square meters per gram the precision is about 1 per cent to 5 per cent.

For the two samples of glass beads listed in Table II, the average bead diameters were estimated from microscopic examination to be 40 and 58 microns. The densities of the two samples were measured by water displacement and found to be 2.444 and 2.798 grams per cubic centimeter, respectively. From the average size and density, the geometrical areas were calculated to be 0.062 and 0.037 square meter per gram, with the assumption that the beads were spherical. The agreement between these values and the averages of the values obtained by the gas adsorption method (0.070 and 0.039 square meter per gram) indicates the accuracy obtainable by the BET method.

In Table III a comparison is made of surface-area values obtained with both argon and nitrogen on the same sample. These data indicate that the two gases yield essentially the same areas and may, therefore, be used interchangeably. For samples of low surface area it is believed that, owing to the smaller effective cross-sectional area of the argon molecule, argon affords a slight advantage over nitrogen in providing a somewhat greater amount of adsorption for an equivalent area coverage.

THE KOZENY EQUATION

In recent years the Kozeny equation has attracted considerable attention as a possible aid in obtaining relationships between certain fluid and electrical flow phenomena associated with porous solids.[8,9,10,11] This equation, which relates surface area to porosity and permeability, can be derived from a consideration of the general laws of fluid flow through capillaries of various shapes and of the surface-area - pore-volume rela-

Table I-B — Surface Areas of Sandstones

Sample No.	Fractional Porosity, f	Permeability K (md)	Surface Area (sq. m. per gm.)	Surface Area (sq. m. per cc. pore vol.)	Surface Area (sq. m. per cc. bulk vol.)	Kozeny textural factor, k	Kozeny surface area (sq. m./g.)	Ratio of Adsorption Area to Kozeny Area	Sample Description
				Upper Wilcox Formation — Eocene Age					
33	0.189	0.48	4.03	45.8	8.66	18.0	0.413	9.8	hard, gray, shly.
34	0.168	0.26	3.54	46.4	7.80	11.2	0.582	6.1	hard, gray, shly.
35	0.207	1.33	3.56	36.1	7.48	25.3	0.246	14.5	hard, gray, shly., w/irr. sh. pln.
36	0.221	17.2	2.93	27.4	6.05	14.8	0.100	29.3	hard, shly.
37	0.197	9.58	2.65	28.6	5.64	15.6	0.107	24.8	hard, shly.
38	0.193	4.93	4.01	44.5	8.58	17.2	0.137	29.3	hard, shly.
39	0.183	0.34	5.10	60.3	11.0	19.6	0.445	11.5	hard, shly.
40	0.156	0.17	5.57	80.0	12.5	11.4	0.629	8.9	dk. gray, very shly.
41	0.158	0.13	5.48	77.4	12.2	11.4	0.734	7.5	dk. gray, very shly.
42	0.184	0.24	5.41	63.6	11.7	11.4	0.700	7.7	dk. gray, very shly.
43	0.190	0.37	6.12	69.2	13.1	12.5	0.570	10.7	gray, shly., w/irr. blk. streaks
44	0.189	571	0.79	9.0	1.70	13.5	0.0139	56.8	crs. grn., slightly shly.
45	0.213	755	1.32	12.9	2.75	11.3	0.0162	81.5	crs. grn., slightly shly.
46	0.219	217	1.17	11.1	2.44	22.2	0.0227	51.5	crs. grn., slightly shly.
47	0.193	94.8	1.59	17.6	3.40	22.5	0.0273	58.2	crs. grn., shly., w/irr. sh. pln.
48	0.223	66.7	3.08	28.4	6.34	12.2	0.0572	53.8	crs. grn., shly.
49	0.223	275	1.36	12.6	2.80	8.3	0.0341	39.8	gray, shly., w/irr. blk. streaks
50	0.211	198	2.75	27.3	5.75	8.3	0.0364	75.5	gray, shly., w/irr. blk. streaks
51	0.209	174	1.49	14.9	3.12	10.0	0.0347	43.0	gray, shly., w/irr. blk. streaks
52	0.202	71.1	2.99	31.3	6.33	11.1	0.0485	61.7	gray, shly., w/irr. sh. pln.
53	0.213	137	3.91	38.3	8.15	10.5	0.0396	98.8	gray, shly., w/irr. sh. pln.
				Middle Wilcox Formation — Eocene Age					
54	0.188	13.0	1.21	13.8	2.60	18.9	0.0765	15.8	tan
55	0.207	37.2	1.42	14.4	2.98	16.5	0.0575	10.0	tan
56	0.068	0.23	1.60	58.1	3.95	8.8	0.160	10.0	gray, shly., w/irr. sh. pln.
57	0.074	0.18	1.43	47.4	3.51	38.5	0.0989	14.5	gray, shly., w/irr. blk incl.
58	0.181	51.7	1.28	15.4	2.78	24.7	0.0316	40.5	gray, shly., w/irr. sh. pln and incl.
59	0.156	15.0	1.96	28.1	4.38	31.8	0.0400	49.0	gray, shly., w/irr. sh. pln and incl.
				Catahoula Formation — Miocene Age					
60	0.234	242	0.72	6.2	1.46	18.7	0.0264	27.2	slightly shly., w/mica incl.
61	0.231	438	0.84	7.4	1.71	9.4	0.0270	31.1	slightly limey and shly., laminated
62	0.193	16.4	1.12	12.4	2.40	11.4	0.0921	12.2	tan, limey, shly.
63	0.205	23.6	1.60	16.4	3.37	11.9	0.0834	19.2	tan, limey, shly.
64	0.249	252	0.56	4.5	1.11	11.0	0.0376	14.9	tan, shly.
65	0.256	357	1.14	8.8	2.25	9.5	0.0359	31.7	tan, shly.
				Chester Formation — Mississippian Age					
66	0.149	24.8	0.39	5.9	0.88	—	—	—	hard, gray, w/irr. sh. pln.
67	0.182	340	0.59	7.0	1.28	7.9	0.0219	27.0	hard, gray, w/irr. sh. pln.
68	0.158	278	0.06	0.8	0.13	—	—	—	hard, gray, w/irr. sh. pln.
69	0.161	45.5	1.38	19.1	3.07	10.5	0.0422	32.7	hard, gray, w/irr. sh. pln.

tionships of such capillaries. For a porous matrix of permeability K md and fractional porosity f, the surface area, S, in square meters per gram of solid, is given by the Kozeny equation as:

$$S = \frac{31.8\, f}{\rho(1-f)} \sqrt{\frac{f}{kK}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

where ρ is the density of the solid (grain density) in grams per cubic centimeter and k is a nondimensional textural factor, the magnitude of which depends in part on the shape of the pores and on the length of the path taken by the fluid in traversing unit length of the porous solid. The utility of Equation (5) has, in the past, been somewhat limited by the fact that k could not be readily evaluated independently of the equation itself except for very simple geometrical configurations of pore space. In general k has been calculated from Equation (5) by making separate experimental measurements of S, ρ, K, and f.

A recent paper by Wyllie and Spangler[11] has indicated that a textural factor suitable for use in the Kozeny equation can be obtained for a given sample from its capillary pressure curve and permeability. Thus,

$$k = \frac{f(\gamma \cos\theta)^2}{9.87 \times 10^{-12} K} \int_{s=0}^{s=1} ds/P_c^2 \quad . \quad . \quad . \quad . \quad (6)$$

where P_c is the capillary pressure in dynes per square centimeter at fractional saturation s, γ is the interfacial tension in dynes per centimeter between the fluids for which the capillary pressure curve is determined and θ is the contact angle formed by the two fluids and the solid. As before, K is the permeability in millidarcys and f the fractional porosity.

Equation (6) has been applied in the determination of textural factors for a series of unconsolidated packs of glass beads. The beads used in these experiments were obtained from the Minnesota Mining and Manufacturing Co. under the trade name, "Scotch-Lite." The beads were carefully sieved and packs made up from each of the available size fractions, as indicated in Table IV. The porosity of each pack was determined from the internal dimensions of the cylindrical tube in which the beads were confined and from the weight and density of the beads. The permeability of each pack was determined by air flow. Mercury capillary pressure curves were determined for the packs, using an apparatus described previously[12] which was modified slightly to enable injection of mercury into the cylinders containing the beads. Typical curves are shown in Fig. 3.

The textural factors, calculated by means of Equation (6) from the permeability, porosity, and capillary pressure data, are given in column 7 of Table IV. These textural factors have been used to calculate the surface area of the beads by the Kozeny Equation (5), and the results are shown in column 8 of Table IV. In addition, the geometrical surface areas of the various packs have been computed from the average bead size (taken as the arithmetical average of the sieve openings) and the glass density, with the results shown in column 9.

A comparison of the Kozeny area with the geometrical area for the various packs indicates the former to be slightly, but consistently, higher than the latter. These differences can be explained in at least two ways: (1) The geometrical areas are based on the assumption that the particles are spherical and although a microscopic examination of the beads indicated this to be a good assumption, it is possible that minor imperfections in the beads cause the true surface area to be somewhat greater than the geometrical area. However, for the one pack (K) where the surface area was sufficiently large to make possible a determination by the gas adsorption method, the average value of the surface area so determined (0.039 sq. m/g) agreed more closely with the geometrical area than with the Kozeny area. (2) In computing the textural factors by means of Equation (6), a value of 140° was assumed for the contact angle of mercury against the glass. If this value is in reality too low, then the reported textural factors are likewise too low and the calculated Kozeny surface areas too high. If a value of 148° had been assumed for θ, then the textural factors would have been 23 per cent greater than those reported in Table IV, and the Kozeny areas would have been 10 per cent less, bringing them into closer agreement with the geometrical areas. It is quite probable that a combination of the two effects discussed above account for the differences between the Kozeny and geometrical areas of the bead packs although, because of the agreement cited above between the geometrical and gas adsorption areas, it is believed that the second of the factors is the more significant. In any event it is believed that the experiments here reported for the bead packs indicate that Equation (6) provides a reliable method for evaluating the textural factor. Although the absolute values of the factors so determined may be open to question because of uncertainties in the value of the contact angle, nevertheless the method should provide very good relative values.

The data presented in Table IV confirm the observations of other workers who have shown that for unconsolidated packs of fairly uniform particle and pore size the Kozeny equation provides a convenient means of obtaining a measure of the surface area. We turn now to a consideration of the applicability of the Kozeny equation to consolidated porous solids as represented by reservoir rocks.

For the sandstone samples listed in Table I-B, textural factors have been determined by means of Equation (6) from permeability, porosity, and capillary pressure data in the same manner as described above for the bead packs. The values of k so obtained have been employed in Equation (5) to calculate surface areas according to the Kozeny formulation. The permeabilities of the core plugs were determined by air flow at several mean pressures between about 1.5 and 7 atmospheres, appropriate corrections being made for gas slippage by the

Table II — Typical Data Showing the Reproducibility of Surface Area Determinations

Sample*	Surface Area (sq. meters per gram) Run 1	Run 2	Per Cent Difference	Adsorbate
Sandstone (40)	5.60	5.55	0.9	Nitrogen
Sandstone (52)	2.98	3.00	0.7	Nitrogen
Sandstone (47)	1.55	1.63	5.0	Nitrogen
Limestone (10)	0.20	0.22	10.5	Argon
Limestone (21)	0.13	0.14	7.4	Argon
Limestone (4)	0.091	0.086	5.6	Argon
Glass Beads 40 microns	0.068	0.072	5.7	Nitrogen
Glass Beads (K) 58 microns	0.037	0.041	10.3	Nitrogen

*Numbers and letters in parentheses refer to Tables I and IV, respectively.

Table III — Comparison of Nitrogen and Argon Surface Areas

Sample*	Surface Area (sq. meters per gram) Nitrogen	Argon
Sandstone	4.5	4.3
Limestone (13)	0.36	0.36
Glass Beads (K)	{ 0.037 0.041	0.039

*Numbers and letters in parentheses refer to Tables I and IV, respectively.

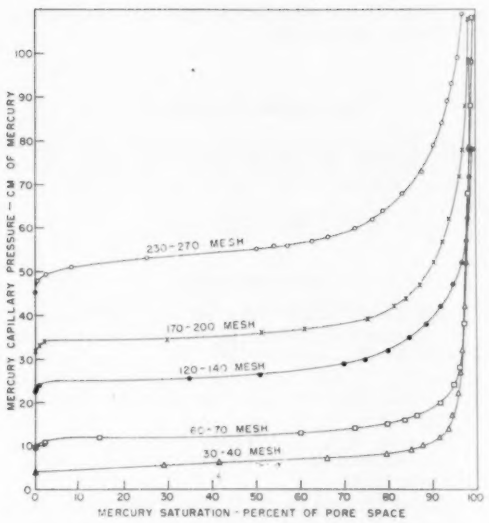

FIG. 3 — CAPILLARY PRESSURE CURVES FOR PACKS OF GLASS BEADS.

method of Klinkenberg.[12] Porosities were determined by saturation of the plugs with an organic liquid.

Two conclusions are immediately apparent from an inspection of the values of the textural factor and of the Kozeny surface area as given in Table I-B. First, the values of the textural factor, which range from about 8 to 40, are considerably higher than the values of 3 to 4 which were found for the glass beads and the value of about 5 previously reported for unconsolidated packs of sorted sand grains.[14] These higher values of k for consolidated sands appear reasonable since it may be expected that compaction and cementation will increase the tortuosity of the porous matrix.

Secondly, it will be observed that the surface areas, as determined by gas adsorption, are from about 5 to 100 times larger than the areas calculated from the Kozeny equation. In considering in detail the gas adsorption and Kozeny methods of determining the surface areas of consolidated porous media, such as reservoir rocks, several reasons are indicated for the divergence of values obtained by the two methods. The Kozeny method can be expected to provide a measure of only the external surface of the solid particles which is contacted by a fluid in moving through the porous solid; whereas, the gas adsorption method should yield a measure of this external area plus any "internal" surface possessed by the solid particles and any surface contributed by "dead-end" pores that hold, but do not transmit, fluid. This difference is well recognized and has indeed already been pointed out by Lea and Nurse[15] and others. In addition to the above, it is believed that lack of uniform pore size may play a considerable part in contributing to the divergent results obtained by the two methods. Carman[16] has listed uniform pore size, together with several other factors, as a condition which must be fulfilled if the Kozeny equation is to yield a significant value of surface area for consolidated media. Intuitively, one can recognize the influence of nonuniformity of pore size in the following way: Consider first a porous solid of uniform pore size that contains no "dead-end" pores and whose surface is entirely available to a fluid which flows through the solid. Secondly, let us alter this system, insofar as the size distribution only is concerned, maintaining the same porosity and textural factor. This could be accomplished, for example, by subdividing just one of the many channels to form several smaller channels with the same shape and length as the original. This would serve to reduce the permeability by only a very small amount* but the surface area of the system could be increased without limit by continuing the subdivision of the one pore indefinitely. In other words the surface area could be altered practically independently of the permeability, whereas the Kozeny equation demands that for a given porosity and textural factor the surface area be inversely proportional to the square root of the permeability. This same point can be illustrated more rigorously by considering the following equation given by Calhoun, Lewis and Newman:[17]

$$S = \frac{10^4 f}{\rho(1-f)(\gamma \cos\theta)} \int_{s=0}^{s=1} P_c ds \quad . \quad . \quad (7)$$

*If n is the original number of pores and K_o the original permeability, then the new permeability, K, approaches $\left(\frac{n-1}{n}\right) K_o$ as n, the number of new pores formed from the single original pore, approaches infinity.

Table IV — Surface Areas of Bead Packs

Pack	Sieve Size Thru	Sieve Size Onto	Average Bead Diam. (cm.)	Fractional Porosity, f	Permeability K (darcys)	Kozeny Textural Factor, k*	Kozeny Surface Area (sq. m/g.)	Geometrical Surface Area (sq. m/g.)	Ratio: Kozeny Area / Geom. Area
A	30	40	0.0505	0.369	218	3.27	0.00548	0.00486	1.13
B	40	50	0.0360	0.361	99.7	3.44	0.00754	0.00682	1.11
C	50	60	0.0275	0.359	41.5	3.16	0.0121	0.00893	1.35
D	60	70	0.0230	0.359	37.9	4.00	0.0112	0.0107	1.05
E	70	80	0.0193	0.349	26.8	3.52	0.0134	0.0127	1.06
F	120	140	0.0115	0.377	11.4	3.39	0.0246	0.0213	1.15
G	140	170	0.00965	0.366	8.90	3.12	0.0273	0.0254	1.07
H	170	200	0.00810	0.394	6.41	3.38	0.0361	0.0303	1.19
I	200	230	0.00680	0.385	4.72	3.30	0.0405	0.0361	1.12
J	200	230	0.00680	0.375	4.12	3.36	0.0406	0.0361	1.12
K	230	270	0.00575	0.379	2.51	3.59	0.0450	0.0373	1.21

*Based on a measured surface tension, γ, of 480 dynes/cm and on an assumed contact angle of 140°.
Density of beads: Packs A thru J — 2.444 g/cm³
Pack K — 2.798 g/cm³

where the symbols have the same definition and units as given previously. Equation (7) accounts for variations in pore size within the porous solid and hence is not limited to systems of uniform pore size. Likewise Equation (6) should be generally valid as a means of determining k for systems of nonuniform, as well as uniform, pore size. By combining Equations (6) and (7) in such a manner as to eliminate the $(\gamma \cos \theta)$ term we find that:

$$S = \frac{31.8\, f}{\rho(1-f)} \sqrt{\frac{f}{kK}} \left(\int_{s=0}^{s=1} P_c\, ds \sqrt{\int_{s=0}^{s=1} ds/P_c^2} \right) \quad \ldots\ldots\ldots\ldots (8)$$

The general Equation (8) reduces to the Kozeny Equation (5) only if

$$\int_{s=0}^{s=1} P_c\, ds = \frac{1}{\sqrt{\int_{s=0}^{s=1} ds/P_c^2}} \quad \ldots\ldots (9)$$

and Equation (9) holds only if the capillary pressure, P_c, has the same value for all values of the saturation, s (i.e., if the pores are all of the same size), a condition that is seldom encountered in reservoir rocks.

Attempts to determine quantitatively the effect of size distribution on the Kozeny equation or to introduce a measure of this property in the equation have so far met with little success. Hence, at the present tme the physical significance of the surface area obtained by the Kozeny equation appears somewhat obscure when applied to porous media exhibiting nonuniform pore sizes.

SUMMARY

Results of surface-area measurements on sedimentary rocks utilizing the low-temperature gas adsorption method have shown that for the numerous samples tested the surface areas of the sandstones ranged from 0.5 to 6 square meters per gram whereas the areas of the limestones ranged from 0.05 to 0.5 square meter per gram. The porosities of the limestones tested were in general lower than those of the sandstones, and when the surface areas were compared on the basis of unit pore volume, rather than unit weight, no significant differences were observed between sandstones and limestones.

Mercury capillary pressure tests on the sandstone samples provided information from which rock textural factors were calculated. These factors were found to range from 8 to 40 as compared to the values of 3 to 4 which were obtained in the same manner for unconsolidated packs of spherical glass beads.

The textural factors have been employed in the Kozeny equation to calculate surface areas from porosity and permeability data. For the bead packs the surface areas so calculated were found to be very nearly equal to the geometrical area of the beads and, in the one instance where a gas adsorption measurement was possible, the Kozeny area agreed fairly well with the BET area. For the sandstones, the Kozeny areas were found to be much smaller than the areas determined by the gas adsorption method.

It is postulated that the lack of uniform pore size in naturally occurring rocks may limit the applicability of the Kozeny equation to such porous solids and may contribute, in part, to the observed differences between the Kozeny and the gas adsorption surface areas.

ACKNOWLEDGMENT

The authors acknowledge with appreciation the assistance of M. I. Palmer, Jr., who carried out the measurements of permeability, porosity, and capillary pressures reported in this paper.

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THE PRESSURE PERFORMANCE OF FIVE FIELDS COMPLETED IN A COMMON AQUIFER

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ABSTRACT

This paper presents the results obtained after calculating matches of the observed pressure performance of five fields completed in a common aquifer. A general description of the Central Basin Platform area in West Texas in which the five fields, Andector, Embar, Martin, TXL, and Wheeler, are located is contained in the paper. The method of utilizing the electric analyzer to calculate simultaneously matches of the observed pressure performance of the five fields is outlined. The determination of boundaries of pressure communication is discussed and the extent of pressure interference between fields consistent with the configuration of the area aquifer is shown graphically.

INTRODUCTION

Anomalies in the pressure performance of the Andector Ellenburger Field resulted in an investigation of pressure interference between several Ellenburger fields located on the Central Basin Platform in West Texas. Four fields, Embar, Martin, TXL, and Wheeler, were found to contribute significantly to the pressure drawdown at Andector.

An initial investigation of the pressure performance of the Andector Ellenburger Field revealed that the reservoir pressure could not be matched by the calculation technique usually applied to water drive reservoirs. In the past, many have advanced the opinion that fracturing in the Ellenburger was a local condition restricted to the immediate uplifted area around the field, in which case each field would in all probability be surrounded by its own relatively small aquifer. Following several unsuccessful attempts to account for the pressure performance at Andector, a system assuming a common aquifer involving several fields in the immediate vicinity of Andector was placed on the electric analyzer and the effect of interfield interference was noted. A refinement of the initial analyzer calculations involved the determination of the approximate boundaries of the aquifer, the calculation of detailed matches of the pressure performance of the interfering fields, and an evaluation of the degree of communication between fields.

DISCUSSION

Geology and Development

The fields considered in this work are located in the Central Basin Platform, a north-south trending structural feature in West Texas lying between the Delaware Basin to the west and the Midland Basin to the east. The locations of various individual Ellenburger fields in this general are shown in Fig. 1 with the five major fields which appear to be definitely intercommunicating colored in black and located in the circled portion of the figure.

Production from the five fields was first obtained from the Embar Field discovered in July 1942, followed by the Wheeler Field in 1943, the TXL Field in 1945, and the Martin and Andector Fields in 1946. The total reservoir fluid production from these fields is indicated in Fig. 2. As illustrated in this figure, very little production was taken from these fields prior

[1]References given at end of paper.

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to 1946, when the total withdrawals began to climb rapidly, reaching a peak of approximately 120,000 reservoir bbl of fluid per day in December 1948.

The Ellenburger formation on the Central Basin Platform in the area under consideration is a dense dolomite approximately 1,000 ft thick. Oil production in the Ellenburger is found on local structural highs generally characterized by a high degree of fracturing. Although some vugs and solution channels are present, the dolomite matrix is dense with a very low porosity and a low permeability on the order of 0.1 md. Several fracture systems are present in the Ellenburger, as indicated by the observation of fresh fractures cutting across secondary deposits in older fracture systems. The fracture observed in the Ellenburger cores are primarily of the jointing type in which there has been little or no displacement parallel to the plane of the break. Pressure communication within fields is generally good and well productivities are high, indicating a relatively high permeability in the fracture system.

It has been previously supposed by many that the fracturing observed in the Ellenburger fields was of a local nature, being confined primarily to the local structural features. This condition, if present, would result in a series of fields surrounded by individual aquifers of limited extent. In such a case, there would probably be no effective pressure communication between fields during their productive history. A survey of available geologic information on the Ellenburger was made in order to determine if any of the available data would actually preclude consideration of continuous permeability and communication between fields. No data of this type were found. On the contrary, an examination of available drill-stem test data on wildcat wells on the central Basin Platform area indicated the presence of appreciable permeability in wells between producing fields. Since very little matrix permeability is present in the Ellenburger, the permeability encountered on the wildcat tests is indicative of an extension of the fracture system away from the producing areas.

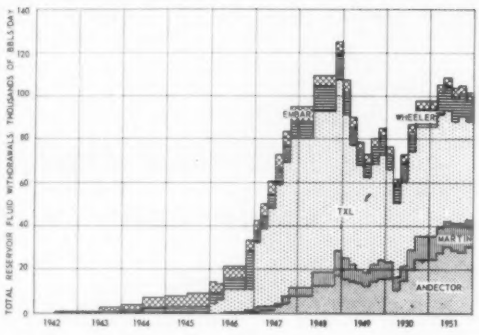

FIG. 2 — DISTRIBUTION OF FLUID WITHDRAWALS FROM FIVE FIELDS IN THE ELLENBURGER AQUIFER.

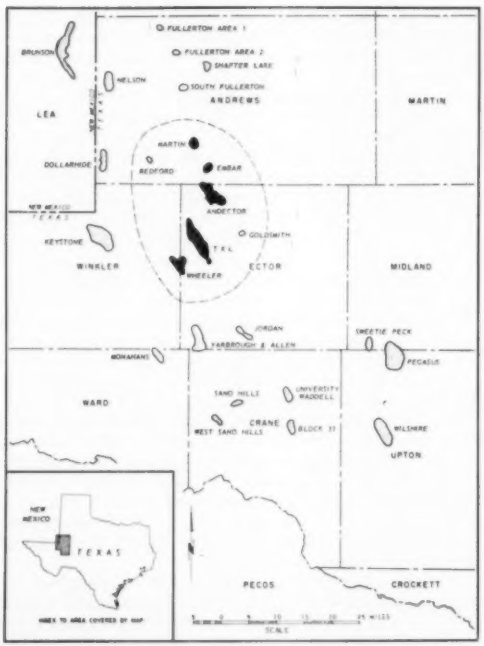

FIG. 1—ELLENBURGER FIELDS IN THE CENTRAL BASIN PLATFORM AREA.

Calculation Technique

The utility of the electric analyzer for appraising the pressure performance of water drive reservoirs has been discussed.[1] The electric analyzer is particularly well suited for evaluating reservoir pressure performance where more than one reservoir is producing from a common aquifer in that it provides a method for simultaneously calculating the magnitude of the pressure drawdown in reservoirs where interference is taking place.

Attempts were made to match the pressure performance of the five major fields on the electric analyzer water drive unit by considering each field individually and withdrawing production from all of the fields at the appropriate location on the water drive network. A discussion of this water drive network and pool unit network calculation technique on the electric analyzer as applied to an aquifer in which more than one field was producing has been published in the literature.[2] Fair pressure performance matches were obtained for Andector,

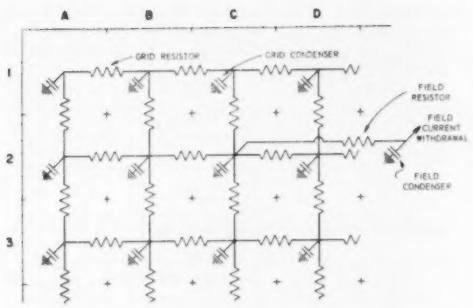

FIG. 3 — ELECTRIC ANALYZER POOL UNIT CIRCUIT DIAGRAM.

Embar, and Martin in this manner, but attempts to obtain pressure matches for the TXL and Wheeler Fields with an electrical representation of the aquifer configuration that appeared to be consistent with that used for the northern three fields were unsuccessful. It was thought that the relative position or porosity pinchouts, could account for the fact that the pressure performance of all the five fields was not matched on the water drive unit. In order to pursue this approach, the five fields and the surrounding areas were depicted through the use of the pool unit on the electric analyzer.

The basic electrical circuit of the analyzer pool unit is shown in Fig. 3. The electric network is set up on a grid pattern so that the pressure in any grid is analogous to the voltage on the condenser. The condenser is analogous to the potential expansibility of the fluids under the grid area, the resistances are analogous to the reciprocal of the permeability, and the current withdrawals from the field condensers are analogous to the fluid withdrawals from the reservoirs. In this study, the individual fields were investigated by separating them from the grid area in which they were located by adding a field resistor and field condenser to the grid condenser, as shown in Fig. 3. The individual reservoir fluid withdrawals were represented by the magnitude of the current withdrawn from the network at the field condenser.

The electrical analogy of the pool unit represents fluid flow in two dimensions and not three dimensions. For this reason, it was necessary to adjust the observed individual field pressures to a common datum. A pressure datum of 6,000 ft subsea was selected at which the original aquifer pressure was estimated to be 3,900 psi. All production data were converted to reservoir barrel fluid withdrawals, as is routine in an electric analyzer study. The sizes of the condensers in the grid areas were determined by assuming equal formation thickness and porosity in the five-field area. The sizes of the field condensers were calculated by taking into consideration the volume and expansibility of the oil in each field. The reservoir pressure in all five fields under consideration has not yet fallen below the saturation pressure for any field, and, for this reason, the coefficient of expansion for the oil in any individual field was held constant.

Fig. 4 illustrates the grid system on the analyzer as it was superimposed on the area being studied. The electric network was then developed to correspond with the location of the fields on the grid. The electrical analogy of the TXL Field, which occupies portions of two grid squares, 6-C and 7-C, was developed by having no resistance between the two grids in which the field falls and withdrawing the field production from a field condenser and field resistor wired to the two grid condensers.

Boundaries of Pressure Communication

The location of the boundaries of pressure communication in the aquifer is important to the calculated pressure behavior of the five fields considered in that they control the agreement between calculated and observed pressure behavior and also the relative magnitude of the pressure interference between

FIG. 4 — ANALYZER POOL UNIT GRID SYSTEM SUPERIMPOSED ON FIVE-FIELD AREA WITH ESTIMATED BOUNDARIES OF PRESSURE COMMUNICATION.

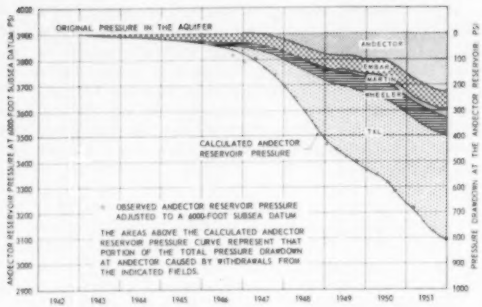
ORIGINAL PRESSURE IN THE AQUIFER
ANDECTOR
EMBAR
MARTIN
WHEELER
TXL
CALCULATED ANDECTOR RESERVOIR PRESSURE
OBSERVED ANDECTOR RESERVOIR PRESSURE ADJUSTED TO A 6000-FOOT SUBSEA DATUM
THE AREAS ABOVE THE CALCULATED ANDECTOR RESERVOIR PRESSURE CURVE REPRESENT THAT PORTION OF THE TOTAL PRESSURE DRAWDOWN AT ANDECTOR CAUSED BY WITHDRAWALS FROM THE INDICATED FIELDS.
ANDECTOR RESERVOIR PRESSURE AT 6000-FOOT SUBSEA DATUM, PSI
PRESSURE DRAWDOWN AT THE ANDECTOR RESERVOIR, PSI
1942 1943 1944 1945 1946 1947 1948 1949 1950 1951

FIG. 5 — ANDECTOR ELLENBURGER PRESSURE PERFORMANCE WITH INTERFIELD INTERFERENCE.

fields. The estimated boundaries of pressure communication, shown in Fig. 4, were determined after an examination of the geologic data available and after trial-and-error calculations of the pressure performance of all five fields. This trial-and-error process consisted of depicting a boundary on the analyzer that would be compatible with geologic data and would also allow the pressure performance history of all five major fields in the aquifer to be matched simultaneously on the analyzer. The boundaries shown represent barriers to pressure communication or fluid flow in the area considered and could be the result of either faulting and displacement of the Ellenburger or of a porosity or permeability pinchout in the aquifer.

The boundaries within the aquifer and in the northern portion of the aquifer are based primarily on geologic data relative to major faulting systems that actually displace the Ellenburger section. The boundaries indicated on the southern edge of the aquifer are based primarily on the pressure production performance of the fields completed in the Ellenburger. For example, it was determined that the Keystone Field, located approximately 12 miles west of the Wheeler Field, was not in communication with the five-field area as a result of the trial-and-error calculations of the field pressure performance. It was not possible to match the pressure performance of Keystone in a system where pressure communication was assumed to exist between Wheeler and Keystone; whereas, the difficulty disappeared when a boundary to flow was assumed to be located between the two areas. A boundary of this type could be due either to faulting or porosity pinchout.

Even though a complex faulting system is located to the south of the five-field area, the location of the estimated boundary of communication in this area is based primarily on pressure performance data. The pressure history of the five-field area indicates that an almost completely closed boundary exists to the south, but it is necessary to maintain a small amount of pressure support from the south or southeast. To date, there has not been sufficient production or pressure drawdown in fields to the south, such as Yarbrough and Allen or Jordan, to determine definitely whether or not they are in partial communication with the five-field area to the north. Even though some of the boundaries or restrictions to flow are indefinite, they represent the configuration of the aquifer as reflected in the pressure performance of the five fields and are consistent with available geologic data.

Calculated Pressure Performance

The resulting matches of the calculated and observed pressure performance for the five major fields within the aquifer system described previously are illustrated in Figs. 5 through 9. Referring specifically to the Andector data in Fig. 5, excellent agreement exists between the calculated and observed pressures with a maximum deviation of 15 lb throughout the last four years of the pressure history. Matches of the calculated and observed pressures are shown for Embar, Martin, TXL, and Wheeler Fields with greater deviation in pressure noted in some instances.

After obtaining the pressure matches for the five fields, the interference effects between the fields were evaluated by selectively withdrawing production from only one field and observing the effects of the withdrawals from this one field on the pressure at each of the other fields. The interference effects of all the fields as observed at any one field are additive and the summation of the pressure drawdown caused by the withdrawals from each individual field is equal to the total drawdown observed in any field. This process of selective withdrawals was continued until the interference between all five fields was evaluated. The relative intereference effects of the five fields on the Andector pressure performance are shown in Fig. 5 as component parts of the total pressure drawdown observed in Andector. It will be noted that production from the Andector Field has caused a reduction in pressure at Andector of only 230 lb as of Jan. 1, 1952, or less than 30 per cent of the total pressure decline of 810 lb observed in that field as of that date. In other words, if none of the fields except

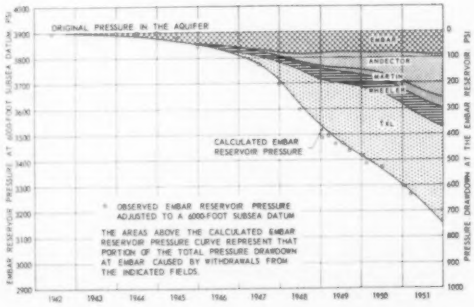
ORIGINAL PRESSURE IN THE AQUIFER
EMBAR
ANDECTOR
MARTIN
WHEELER
TXL
CALCULATED EMBAR RESERVOIR PRESSURE
OBSERVED EMBAR RESERVOIR PRESSURE ADJUSTED TO A 6000-FOOT SUBSEA DATUM
THE AREAS ABOVE THE CALCULATED EMBAR RESERVOIR PRESSURE CURVE REPRESENT THAT PORTION OF THE TOTAL PRESSURE DRAWDOWN AT EMBAR CAUSED BY WITHDRAWALS FROM THE INDICATED FIELDS.
EMBAR RESERVOIR PRESSURE AT 6000-FOOT SUBSEA DATUM, PSI
PRESSURE DRAWDOWN AT THE EMBAR RESERVOIR, PSI
1942 1943 1944 1945 1946 1947 1948 1949 1950 1951

FIG. 6 — EMBAR ELLENBURGER PRESSURE PERFORMANCE WITH INTERFIELD INTERFERENCE.

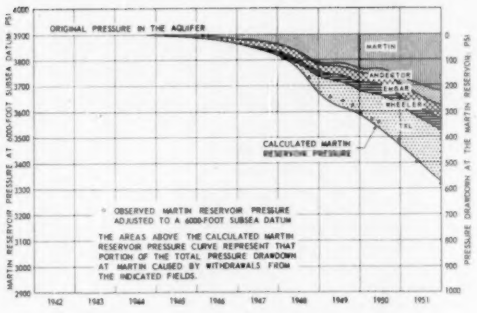
ORIGINAL PRESSURE IN THE AQUIFER
MARTIN
ANDECTOR
EMBAR
WHEELER
TXL
CALCULATED MARTIN RESERVOIR PRESSURE
* OBSERVED MARTIN RESERVOIR PRESSURE ADJUSTED TO A 6000-FOOT SUBSEA DATUM
THE AREAS ABOVE THE CALCULATED MARTIN RESERVOIR PRESSURE CURVE REPRESENT THAT PORTION OF THE TOTAL PRESSURE DRAWDOWN AT MARTIN CAUSED BY WITHDRAWALS FROM THE INDICATED FIELDS.
MARTIN RESERVOIR PRESSURE AT 6000-FOOT SUBSEA DATUM, PSI
PRESSURE DRAWDOWN AT THE MARTIN RESERVOIR, PSI

FIG. 7 — MARTIN ELLENBURGER PRESSURE PERFORMANCE WITH INTERFIELD INTERFERENCE.

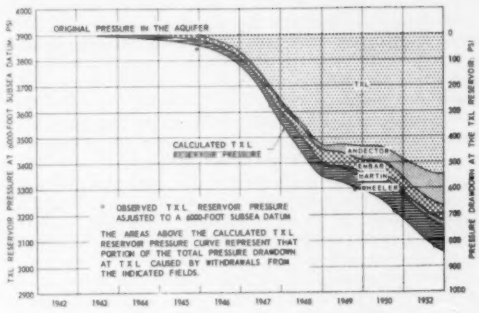
ORIGINAL PRESSURE IN THE AQUIFER
TXL
CALCULATED TXL RESERVOIR PRESSURE
ANDECTOR
EMBAR
MARTIN
WHEELER
* OBSERVED TXL RESERVOIR PRESSURE ADJUSTED TO A 6000-FOOT SUBSEA DATUM
THE AREAS ABOVE THE CALCULATED TXL RESERVOIR PRESSURE CURVE REPRESENT THAT PORTION OF THE TOTAL PRESSURE DRAWDOWN AT TXL CAUSED BY WITHDRAWALS FROM THE INDICATED FIELDS.
TXL RESERVOIR PRESSURE AT 6000-FOOT SUBSEA DATUM, PSI
PRESSURE DRAWDOWN AT THE TXL RESERVOIR, PSI

FIG. 8 — TXL ELLENBURGER PRESSURE PERFORMANCE WITH INTERFIELD INTERFERENCE.

Andector had been discovered, the pressure in Andector on Jan. 1, 1952, would have been 3,670 lb at 6,000 ft subsea, 580 lb higher than the adjusted pressure of 3,090 lb at 6,000 ft subsea. The pressure in Andector as of Jan. 1, 1952, has been reduced 80 lb by withdrawals from Embar, 30 lb by withdrawals from Martin, 75 lb. by withdrawals from Wheeler, and 405 lb by withdrawals from TXL. Thus, the withdrawals from the other four fields in the aquifer have resulted in slightly more than 70 per cent of the total pressure decline observed at Andector.

Similar intereference effects on the other four fields are shown in Figs. 6 through 9. As will be noted from these illustrations, the withdrawals from the smaller fields, such as Embar, Martin, and Wheeler, have had relatively little effect on either their own pressure or on the aquifer pressure. The major portion of the pressure reduction within the aquifer has resulted from withdrawals from Andector and TXL, with TXL alone being responsible for a substantial portion of the pressure decline throughout the aquifer up to Jan. 1, 1952.

Two small Ellenburger fields, Bedford and Goldsmith, are located within the boundaries of pressure communication shown on Fig. 4. Bedford Field is located approximately 10 miles west of Embar Field and would fall in Grid 3-B. A match of the pressure performance of the Bedford Field, in conjunction with the general pattern of interfield interference, was not obtained. The pressure at Bedford is primarily the result of fluid withdrawals from the field itself and is attributed to a local permeability condition. Goldsmith Field is located approximately seven miles east of TXL and falls in Grid 7-E. A satisfactory match of the pressure in this field was obtained with the pressure drawdown attributed almost entirely to the pressure interference from nearby major fields, particularly TXL and Andector.

The calculated isobaric pattern effective Jan. 1, 1952, is shown in Fig. 10. This isobaric map was constructed by referring to the calculated pressure in the grid areas represented on the pool unit of the electric analyzer. As indicated on this illustration, the pressure profile throughout the aquifer is relatively flat with a maximum differential in pressure of 400 lb in an area approximately 35 miles in length and 20 miles in width. This degree of pressure communication throughout an area of this magnitude is indicative of a relatively high order of permeability throughout the aquifer. The analyzer results indicate that the aquifer has a mean permeability of approximately 50 md.

The discovery well of the Block 12 Ellenburger Field, Phillips' University Well EE-1, has been drilled early in 1952 within the estimated boundaries of communication for the five-field area. A pressure of approximately 3,320 lb adjusted to a 6,000-ft subsea datum was measured in the well in April 1952. This discovery is located approximately seven miles west of Martin Field and would fall in Grid 2-B near the 3,400-lb contour on the isobaric pattern effective Jan. 1, 1952. At the rate of pressure decline in the aquifer calculated during 1951,

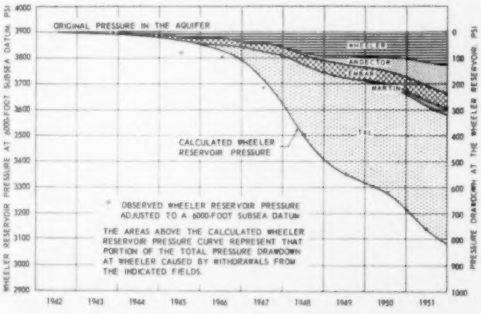
ORIGINAL PRESSURE IN THE AQUIFER
WHEELER
ANDECTOR
EMBAR
MARTIN
TXL
CALCULATED WHEELER RESERVOIR PRESSURE
* OBSERVED WHEELER RESERVOIR PRESSURE ADJUSTED TO A 6000-FOOT SUBSEA DATUM
THE AREAS ABOVE THE CALCULATED WHEELER RESERVOIR PRESSURE CURVE REPRESENT THAT PORTION OF THE TOTAL PRESSURE DRAWDOWN AT WHEELER CAUSED BY WITHDRAWALS FROM THE INDICATED FIELDS.
WHEELER RESERVOIR PRESSURE AT 6000-FOOT SUBSEA DATUM, PSI
PRESSURE DRAWDOWN AT THE WHEELER RESERVOIR, PSI

FIG. 9 — WHEELER ELLENBURGER PRESSURE PERFORMANCE WITH INTERFIELD INTERFERENCE.

the pressure in the area of this well would be approximately 3,360 lb as compared with the observed pressure of 3,320 lb. Since the observed pressure is 580 lb lower than the estimated original aquifer pressure of 3,900 lb at 6,000 ft subsea, the agreement between the observed and calculated pressure is considered good.

In summarizing the results of this study, it is pointed out that a match of the pressure performance of a water drive reservoir is only one of the several considerations involved in a complete reservoir study made for the purpose of translating an understanding of the reservoir behavior into operating recommendations. In a large majority of previous reservoir studies, apparent satisfactory matches of pressure performance have been obtained without considering the effect of pressure interference among fields producing from a common aquifer. It is realized that the interference effect in most aquifers has only an insignificant bearing on the results obtained using the simple, direct unsteady state solution of pressure performance. However, in the case of limited aquifers, such as the one discussed in this paper, pressure interference may be of such magnitude that the normal approach is entirely inadequate for calculating reasonably accurate pressure predictions. The results of this study further illustrate the utility of the electric analyzer in obtaining solutions to problems of this general type.

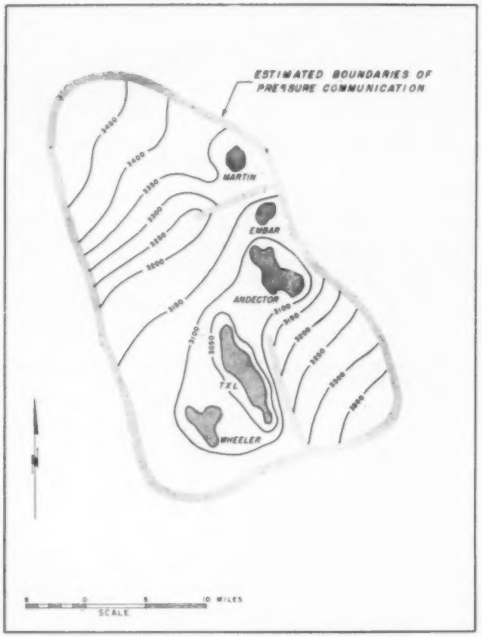

FIG. 10 — CALCULATED ISOBARIC PATTERN EFFECTIVE JAN. 1, 1952.

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A METHOD OF PERFORATING CASING BELOW TUBING

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ABSTRACT

The introduction in the field of a new type well completion called for the setting of tubing open-ended in the well before perforating the casing. This paper describes a new perforating tool of the shaped charge expendable type, small enough to pass through tubing and powerful enough to perforate the casing. The perforations are produced at an angle and are large enough for optimum production. Performance of this tool in targets and under various well conditions is described.

Very often no lifting equipment will be available at the well. In some cases, pressure will exist in the well at the time of the perforating operation (workover wells or multiple trip perforation); therefore, new equipment and new technique for the perforating operation were devised. This paper describes this equipment and technique, particularly casing collar recording, sheave support, and cable pull-down device, this last item being necessary for wells under pressure. Results obtained with this tool in the field are given.

INTRODUCTION

One of the key requirements for the introduction in the field of a new method of permanent well completion was the development of a new perforating method involving the use of a perforating gun small enough to go through tubing and with enough penetrating power to perforate the casing satisfactorily.

The equipment described in this paper was basically designed to go through open-ended two-in. tubing and to perforate 5½-in. casing. The equipment is illustrated in accompanying figures.

NEW COMPLETION METHOD

With the new permanent type well completion, the production string of casing is run and cemented through the potential producing zone. Open-ended tubing is then run into the well and used to replace the drilling fluid with oil or water. The amount of the oil or water "cushion" can be varied according to the expected bottom hole pressure. Thus, if desired, the hydrostatic head can be greater, equal to, or less than the expected pressure within the zone to be perforated.

Mud having been displaced, the tubing is then positioned so that the end is above the zone to be perforated.

The Christmas tree and flow lines are installed and tested. The drilling rig can now be removed from the well since it is not necessary for the perforating operation, thus resulting in a saving in rig tme. The perforating equipment is then moved to the well and the gun lowered through the tubing. After the gun passes out of the open end of the tubing, the depth measurements are correlated with casing collars and the gun placed opposite the zone to be perforated. Upon firing, the gun body is shattered and falls to the bottom of the well. Since the lubricator has been closed before firing, it is possible to withdraw the casing collar locator and head and then open the well immediately to the tanks.

DESCRIPTION OF GUN

An investigation of two basic types of perforators, namely a bullet perforator and a shaped charge gun, was undertaken towards the development of a gun to meet the aforementioned requirements.

Preliminary tests on various bullet perforator designs within the diameter limitations did not give results encouraging enough to warrant further study.

Somewhat better results were obtained by using conventional shaped charges; but, as in the case of the bullet types, the necessarily small overall diameter proved to be a severe limitation and resulted in insufficient penetration.

A shaped charge employing a new design was developed which gave excellent penetration. These shaped charges were designed to produce a large hole directed upward at a 45° angle.

In order to obtain the maximum space possible for these charges, it was decided to use an expendable carrier made of drillable material, usually aluminum, which would shatter at the time of firing, leaving only harmless fragments at the bottom of the hole. The fixed spacing is five shots per ft, with

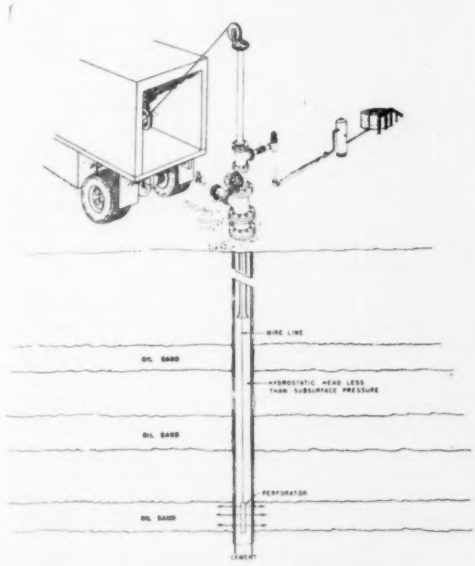

FIG. 1 — PERFORATING FOR ORIGINAL COMPLETION.

References given at end of paper.
Manuscript received in the Petroleum Branch office Aug. 21, 1952. Paper presented at the Petroleum Branch Fall Meeting in Houston, Tex., Oct. 1-3, 1952.

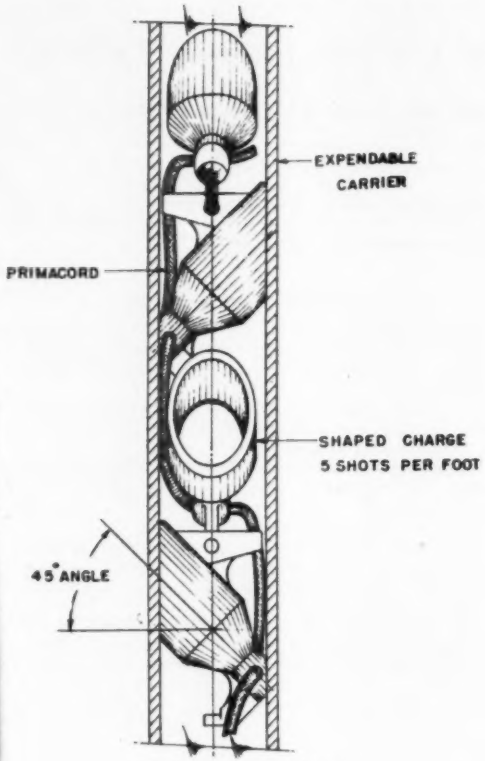

FIG. 2 — GUN CROSS SECTION.

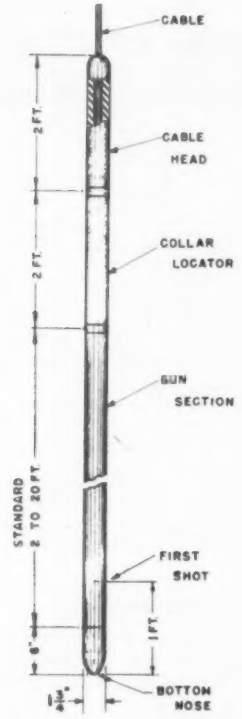

FIG. 3 — COMPLETE GUN ASSEMBLY.

a spiral pattern for the holes, and all charges are fired simultaneously. A sketch of the perforator is shown in Fig. 2.

The outside diameter of the aluminum carrier is 1¾-in., which allows passage through clean 2-in. tubing. The length of the gun is determined by the interval to be perforated. The carrier will withstand a bottom hole pressure up to 4,000 psi. However, due to the low hydrostatic head pressure encountered at the time of completion, this has not been found to be a limiting factor in the use of this gun. A dimension sketch of the complete gun assembly is shown in Fig. 3.

In cases of higher bottom hole pressure, 1¾-in. brass carriers have been used for running through 2-in. tubing, maximum pressure 7,000 psi. When 2½-in. tubing is used, the carrier can be made from heavy wall aluminum pipe able to withstand up to 9,000 psi.

LABORATORY TESTS VS. FIELD EXPERIENCE

Figs. 4 and 5 show the results obtained in laboratory targets by firing the angle shooting shaped charge in the carrier under water with a standoff of ½ in. Other laboratory tests prove that when this gun is fired, no damage to casing results, even when the casing is unsupported.

It is most interesting to find, however, that field performance has proven that in many cases, penetration has exceeded that anticipated from laboratory tests, for instance, perforating through 2-in. tubing and 5½-in. casing.

Since excellent production was recorded, a theory has been advanced that in cases of unconsolidated sand backing the cement sheaf, there is localized fracturing of the cement due to the wedge effect when shooting at an angle.

CASING COLLAR LOCATOR

In order to obtain accurate perforating depths and to give the oil company a permanent record of the tubing and casing setting, a casing collar log is essential.

A special magnetic casing collar locator was designed with a diameter of 1¾ in. to go through 2-in. tubing. This tool not only gives a clear record of the casing collars, the end of the tubing, and the tubing joints, but it also gives a clear indication of the packer back of the tubing (see Fig. 6). The collar locator comprises two magnetic circuits in opposition and a coil in between. Any unbalance in the magnetic circuits, for instance a casing collar, produces in the coil a transient voltage which is transmitted through the cable to the surface recorder.

Signals on the recorder while going down serve as a definite indication of the downward motion of the gun, eliminating the possibility of the piling up of cable in the well if the gun should be stopped by an obstruction.

PREPARATION OF THE WELL

New Wells

1. Perforating Zone in Regard to Total Depth: The gun is designed so that there is a distance of one ft from the bottom charge to the gun end. Therefore, this amount of clearance is necessary between the lowest perforating point and total depth. In actual field practice, it is recommended that this distance be at least two or three ft.

   In the use of this perforator for the completion of new wells, certain steps must be taken.

2. Tubing Setting with Reference to Production Zone: The tubing should be set at least 10 ft above the zone to be perforated. Preferably enough open casing should be left for the recording of casing collars.

3. Hydrostatic Head of Fluid: If the pressure of the zone to be perforated is known, it is advantageous to keep the fluid level low enough so that the hydrostatic head will be smaller than the formation pressure. However, pressure should not be decreased to a point permitting violent pressure differentials at the time of shooting which could damage the reservoir.

   In the case of a new sand of unknown pressure, a safe hydrostatic head can be applied within the limitation of the collapsing pressure of the gun. It should be pointed out that some method of fluid removal should be provided, such as gas lift valves, straight gas injection, or a swabbing unit to remove the excess fluid after perforation.

4. Gauging Tubing for Gun Clearance: A very important phase of the operation is the preparation of the tubing string. It is recommended that a gauge be run through the joints of tubing before they are run into a well. This will eliminate any crooked or "tight" joints that would give trouble in the well. It should be remembered that any gas lift valves, packer mandrels, or other devices installed in the tubing string should have a clearance equivalent to the inside diameter of 2-in. tubing.

5. Closure of Tubing End Subsequent to Perforating: Since some operators will have objections to leaving the tubing open-ended, a removable tubing stop can be installed. It will be necessary to provide a seating nipple for this device at the down-well tubing-end before running the tubing into the well.

   A sketch of one type of landing nipple and tubing stop is shown in Fig. 7. The stop is pushed down the tubing after the perforating operation. It can be removed at any time by use of a standard wire line fitted with a standard 2-in. pulling tool.

6. Cleaning Well Opposite Zone to be Perforated: The cleaning of the well in preparation for the perforating operation is highly desirable in this type of completion. After cementing the casing, the tubing is installed and the displacement of the drilling fluid begun. In order to eliminate the possibility of heavy mud at the bottom, sufficient extra tubing should be placed in the string to assure a washing action below the depth to be perforated. A thorough washing of

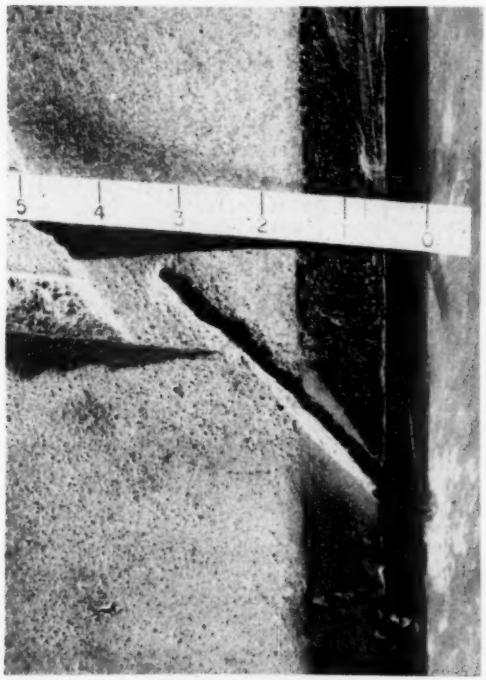

FIG. 4 — CLOSE-UP OF TEST TARGET SHOWING JET PATH.

FIG. 5 — CLOSE-UP OF TARGET. STEEL: ½ IN. N-80. CEMENT: NEAT CEMENT. BACKING: ¼ CEMENT, ¾ SAND. NOTE HAIRLINE CRACKS.

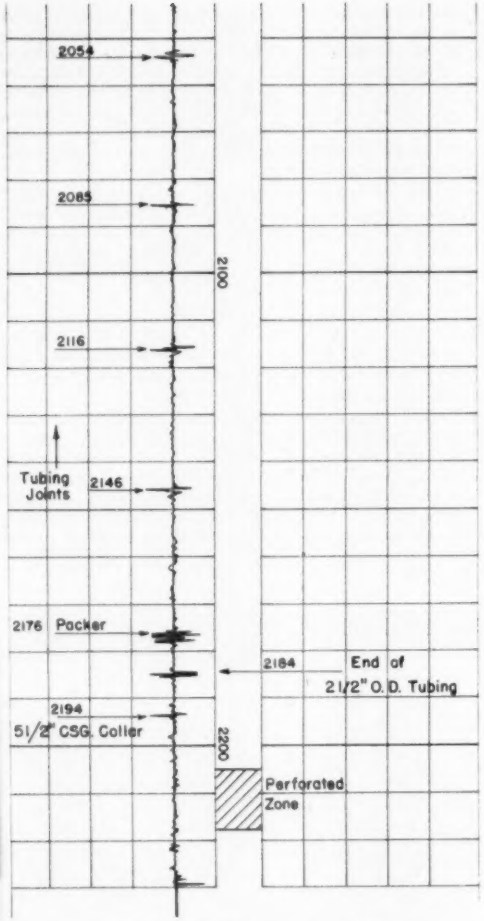

FIG. 6 — TYPICAL CASING COLLAR LOG.

the well will eliminate any cuttings settling in the lower part of the well. It will also insure the removal of mud and other foreign particles from the inside of the tubing string.

7. Check Points in Casing Below Tubing: In setting the tubing, the uncovering of at least two check points, such as casing collars or other known points, will be an advantage in correlating depth measurements.
8. Use of Tubing Packer: If a tubing packer is used, it is an advantage to use one of the types that do not require downward weight for their operation since any bending of the tubing above the packer could prevent the passage of the gun.
9. Placement of Fluid Cushion: The fluid to be placed within the tubing can be oil, fresh water, or salt water. Salt water has been found the least desirable from the standpoint of obtaining a clean opening through the tubing consistently.

After the tubing is in place, the well head can be installed and the drilling rig moved off the location if desired. In the event that a series of zones are to be shot and tested, it may be advisable to perforate with the drilling rig over the well.

Workover Wells

The preparation of a workover well for this type of perforating will differ from the procedure used on a new well.

1. Removal of Tubing End: The first consideration in this type of well is the removal of the tubing end. There are three methods for accomplishing this removal. They are (a) Withdrawal of tubing, (b) Opening tubing end by use of wire line tools and "jars," (c) Opening of tubing end by means of special explosive charge.
2. Elimination of Tubing Pressure at the Well Head: In many types of workover operations, this tubing pressure may be non-existent because the well is "dead" or because work on the well with drilling equipment has necessitated the killing of the well. In cases where the operator is unsuccessful in eliminating the pressure, a special method, described later in the paper, will have to be used.
3. Gauging for Tubing: The third factor in workover jobs is the gauging of the tubing to verify that sufficient clearance exists for the passage of the gun. This operation is especially important in wells where the tubing has not been pulled. It has been found on many occasions that the inside

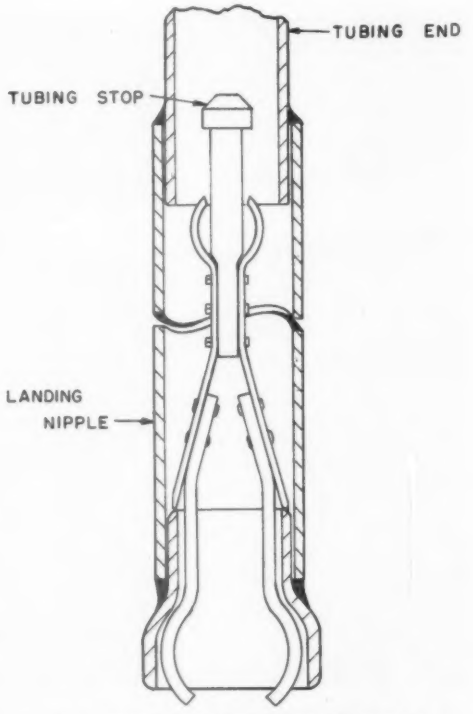

FIG. 7 — SEATING NIPPLE WITH TUBING STOP IN PLACE.

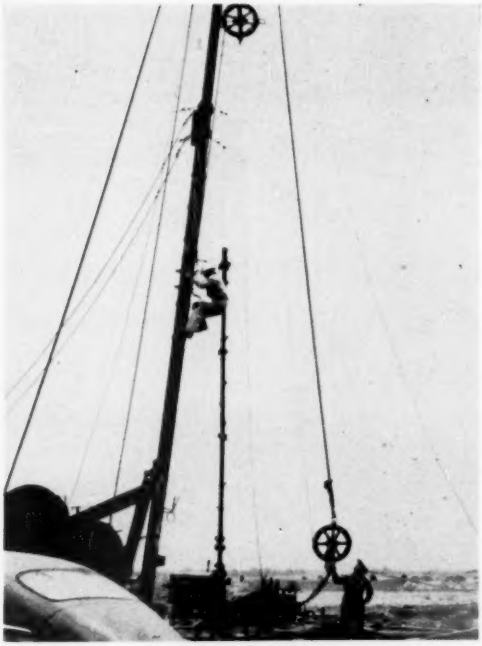

FIG. 8 — SWABBING UNIT.

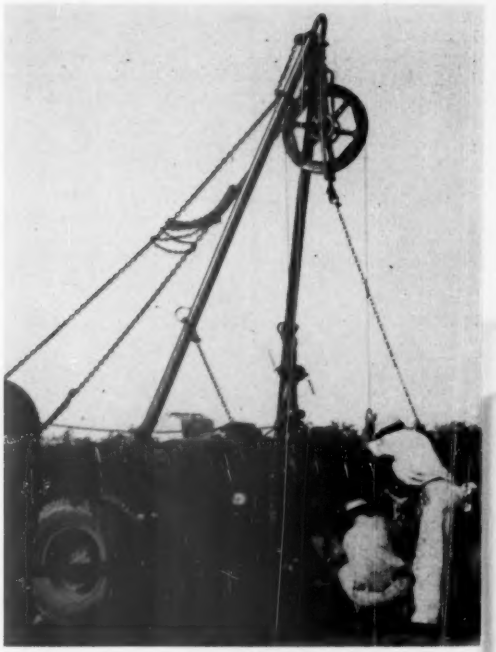

FIG. 9 — A-FRAME TRUCK.

of the tubing was coated with paraffin, scale, or salt, preventing descent of the gun to shooting depth.

The length of the wire line gauge used should be at least equal to the length of the gun and the cable head planned for perforating. In the event a wire line tool is used to remove the tubing end, then the tubing gauging can be carried on at the same time. In addition, the wire line can be used to check the casing below the tubing end for possible fill-up.

4. Placement of Fluid Cushion: The placing of fluid in the well is the same operation as that described previously. However, in some cases, the well itself can be allowed to "load-up" and thus produce its own hydrostatic cushion. It is recommended in all cases to keep a minimum of 40 ft of fluid above the zone to be perforated to avoid damage to the perforating equipment. In most workover wells, the pressures to be encountered are definitely known, allowing the use of a differential pressure into the well bore. When properly applied, this method will eliminate the need for swabbing or other similar operations to bring the well in.

FIELD OPERATION

Sheave Support for Shooting Line and Perforator

Auxiliary surface equipment is necessary to support the sheave for the cable, for the lifting of tools, and the erection of the lubricator. If the derrick is available at the well, it is possible to use standard perforating line and trucks. If no derrick is available, a tubing pulling unit, the mast of a swabbing unit (Fig. 8), or even an A-frame or "gin pole" truck can be used as shown on Fig. 9. This use of a gin pole truck has proven to be very economical in workover wells on which it is unnecessary to remove the tubing.

In some cases, mostly in workover wells, such devices are not available. To provide for this type of operation, a light perforating truck equipped with a small 3/16-in. diameter armored cable has been designed. The cable and upper sheave are supported by the lubricator. The lifting equipment is carried disassembled on the truck and is used in the following manner:

1. On wells that do not have pressure on the tubing, a simple arrangement can be used, as shown in Fig. 10. Since any arrangements for sealing against pressure must be made only after the well is shot, the lubricator is made only long enough to contain the cable head and collar locator.

   A light "gin pole" is mounted parallel to the lubricator and is used to lower the gun into the well.
2. In case of pressure in the tubing at the time of the first or of successive trips in the hole, a 30-ft portable derrick is erected, as shown on Fig. 11. This arrangement has been used with good results, but increases the time required for the perforating operation because of the need for erecting a derrick, and also the fact that the 16-ft maximum length of the lubricator limits the length of the gun, thus reducing the number of shots possible in one trip. When the pressure exceeds 150 psi, a special wire line stuffing box and cable feeder device are required.

Pressure Sealing Equipment

As the perforator has a small diameter, the pressure sealing equipment is also of a smaller size. A sketch of a section of

FIG. 10 — SIMPLE GIN POLE SET-UP.

FIG. 11 — PORTABLE DERRICK AND FULL RISER.

the lubricator is shown in Fig. 12. The body of the lubricator is made of 2½-in. tubing fitted with quick connecting 3,000 psi unions. The blowout preventer is the ram type with a full 2½-in. opening. The stuffing box is the split rubber packed type with design modifications for grease injection. All of the equipment is tested to 3,000 psi cold water pressure.

When perforating a well under pressure, a full lubricator must be used. In addition, the stuffing box is grease packed continuously and requires careful adjustment. A cable feeder is installed at the top of the lubricator and feeds the cable into the well until the cable weight will overcome the upward thrust due to well pressure. Because of this upward force, this operation has only been performed with the 3/16-in. cable. A sketch of the cable feeder is shown in Fig. 13. To date, this operation has been on a limited basis because of the many difficulties involved.

SHOOTING OPERATION

The gun is loaded five shots per ft to cover a length equivalent to the zone to be perforated. The maximum length of carrier used up to date has been 31 ft containing 155 shots.

The cable with the casing collar locator and gun attached to the head assembly are lowered into the well. The downward motion of the gun is checked by the casing collar locator readings and in addition by the weight indicator.

When total depth is reached, a casing collar log is made, recording upward until a maximum of two or three joints of tubing are located. This log is then a permanent record of the depth of perforation relative to casing collars. If other logs are available, it is possible to correlate the placement of perforations accurately within the zone to be shot with reference to depth.

The gun is then located at the shooting depth by watching both the depth indicator and casing collar recorder. The lubricator is closed and the current is applied to the gun, shooting all charges at once. Definite indication of the shooting is given by the listening circuit.

The casing collar locator and head are pulled up into the lubricator. The well valve can be closed and the cable head and lubricator removed. The well can now be opened immediately to the regular production equipment since there is no mud in the tubing.

At the time of the shooting, the carrier falls to the bottom of the well in the form of a distorted tube in one or more pieces. While the well is in production, the remnants of the carrier will be attacked by acid or salt water. This is illustrated in Fig. 14, which shows the distorted tube after two weeks in a well.

In Fig. 15, it is shown that only fragments are recovered in a well after three months. The pieces were washed out of the well by the mud circulation in a subsequent workover operation.

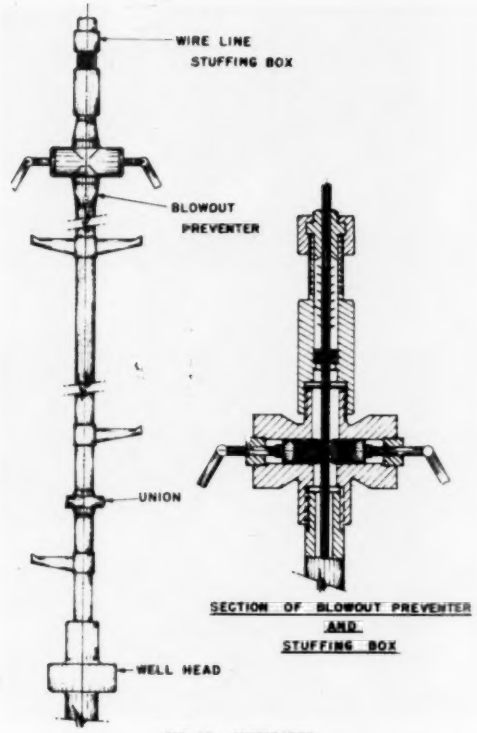

FIG. 12 — LUBRICATOR.

FIELD PERFORMANCE

During the past ten months, over 400 wells have been perforated following this procedure and successfully completed. A summary of these operations is shown in Table I.

In many cases, wells completed by this method have had a higher potential than wells completed by conventional methods. The reason for these results seem to be:

1. The penetration of the specially designed shaped charge and the employment of angle shooting.
2. Perforating and completing the well under optimum reservoir conditions. Since only a slight differential pressure exists between the formation and the bore hole at the time of shooting the formation is not contaminated by the drilling fluid. Normally, the existing differential pressure will be directed toward the bore hole, permitting an immediate flushing of the perforation and a free path for production. Moreover, no contaminating fluid need ever touch the formation subsequent to perforating because it is unnecessary to load the well with fluid at any time during the completion operation.

It is also gratifying to find that even though the tool has been used in cases where extreme penetration was required, only in very few cases has the gun failed to penetrate. The tool used in all operations to date was primarily intended for shooting 5½-in. casing; and while excellent results were obtained in larger casings, a gun specially designed to go through

Table I — Summary of Work to Date

Normal Operations

Ninety-five per cent of the wells were run under the following conditions:

Formations Perforated — Gulf Coast Sands

Depth — From 2,000 to 9,000 ft; averaging 4,500 ft.

Casing — Typical 5½ in., 15.5 lb.

Tubing—50 per cent 2-in. tubing; 50 per cent 2½-in. tubing.

Hydrostatic Head Pressure — Less than formation pressure in all cases. (Under normal conditions, this operation would have required a full column of fluid.)

Number of Shots — Maximum in a well 250
Minimum in a well 20
Average 50

Type of Completion — New wells 40 per cent of the jobs
Workovers 60 per cent of the jobs

Performance — Effective penetration obtained on 99 per cent of all operations.

Outstanding Operations and Special Applications

Deepest Well — 9,916 ft; 2-in. tubing; 50 shots.

Greatest Number of Shots — 155 shots in one gun below 2½-in. tubing, 7,750 ft.

Toughest Penetration — 5-in. liner in 9⅝-in. underreamed hole, 2-in. tubing, 50 shots.

Highest Hydrostatic Pressure — Perforating a well with 18 lb/gal mud at 8,837 ft; pressure 8,450 psi — 25 shots.

Two Strings of Pipe — 2-in. tubing cemented inside of 5-in. liner; 50 shots; well flowed 101 B/D.

Perforating Under Pressure — Ran into well with tubing pressure of 1,040 psi; 50 shots; increased gas production 22 per cent.

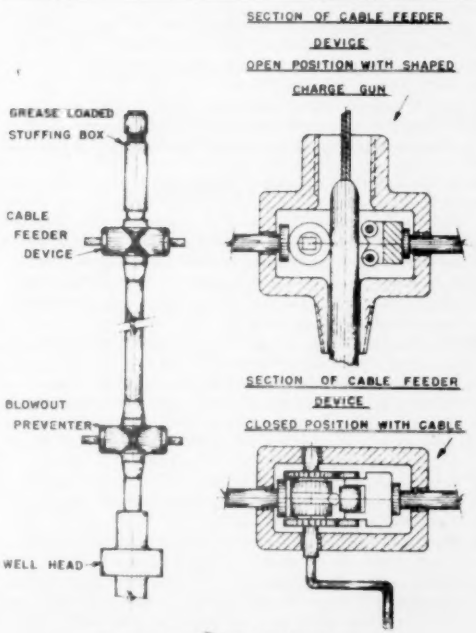

FIG. 13 — ARRANGEMENT OF CABLE FEEDER.

FIG. 14 — DISTORTED TUBE AFTER SHOOTING.

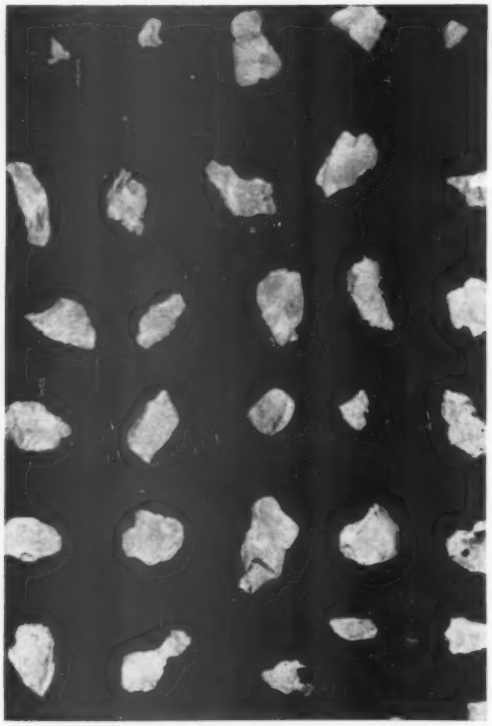

FIG. 15 — FRAGMENTS RECOVERED THREE MONTHS AFTER SHOOTING.

2½-in. tubing and for the shooting of 7½-in. or larger casing is presently being studied. Preliminary tests on this gun show that an increase of penetration of 50 per cent can be expected.

CONCLUSIONS

It is believed that the use of this new perforator in the permanent type completion practices has the following advantages over the present field completion and workover practice:

1. Better production can be obtained in low pressure reservoirs since no mud touches the formation after perforation. Field results confirm this.
2. The use of this tool results in substantial savings on workover jobs since there is no need to move a rig on location. There is also a substantial saving in mud costs since it is not necessary to load the well with mud before perforating.
3. On new wells, substantial saving in rig time can be effected since the rig can be moved off the location prior to perforating and completing.
4. It is possible with this gun to shoot a very large number of shots in one trip, thus eliminating time-consuming multi-run perforation.
5. By permitting the setting of the tubing prior to perforation, it eliminates some of the dangers always present when trying to complete wells for production after standard perforating procedure. All operations are conducted with pressure handling equipment in place on the well, thereby eliminating danger of blowouts or accidents.
6. A safer practice of reperforating workover wells results with the use of this perforator because the well does not have to be killed or the tubing removed.
7. In cases where, due to accidental setting of drill pipe or tubing in the well, conventional perforating tools cannot be used, satisfactory production can often be obtained by shooting with this new gun; whereas in the past such wells would have had to be abandoned or side tracked. This has been proven by several successful jobs in the field.

ACKNOWLEDGMENT

The authors wish to express their appreciation to the Humble Oil and Refining Co. for the use of diversified wells for initial tests and for furnishing field data necessary to the first development of the perforator. They also wish to thank other members of the Schlumberger Well Surveying Corp. for their cooperation.

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FURTHER DISCUSSION OF PAPERS PUBLISHED IN TRANSACTIONS, VOLUME 195 (1952)

ENGINEERING STUDY OF THE COOK RANCH FIELD, SHACKELFORD COUNTY, TEXAS

WALLACE W. WILSON, CONTINENTAL OIL CO., PONCA CITY, OKLA., MEMBER AIME

(Published as T.P. 3285, Page 77)

DISCUSSION

By Henry J. Welge, Carter Oil Co., Tulsa, Okla., Member AIME

This paper calls to attention for the first time, to the writer's knowledge, a purported recovery of oil by substantially horizontal gas cycling that is considerably in excess of 50 per cent of the oil originally in place. The average angle of dip along the path of travel of the gas is less than one degree of arc. The best recovery by gas cycling previously brought to the writer's attention[1] occurred in the case of the Mile Six Field in Peru, where about 68 per cent of the original oil in place has so far been recovered. In this case, however, the recovery was greatly aided by the high dip angle of about 17.5°. An approximate estimate of recovery was made by the method developed by the writer[1] for the case of the Cook Ranch Field, using an average relative permeability ratio function dictated by past experience with a number of good quality sandstones. A result of about 40 per cent recovery of the original oil in place was obtained after the 8.5 pore volumes of cumulative gas cycling undergone by the Cook Ranch Field.

The writer desires to emphasize what appears to him as the sound engineering practiced at Cook Ranch, and also the care attending the taking of data and the high quality of the calculations made. It is impossible to take issue on factual grounds with any of the conclusions drawn in the paper. It is, however, desired to point out the difficulty of explaining the unexpectedly favorable oil recovery on ordinary theoretical grounds. It would be of interest to know whether relative permeability ratios have been measured on the Cook sand. The operator is inclined to attribute some of the excess benefit to settling of the oil across the bedding planes into the lower part of the sand. It is difficult for the writer to appreciate the importance of such an effect, inasmuch as the concomitant opening of excessive vacated pore space in the upper part of the sand would be expected to cause excessive bypassing of the gas.

REFERENCE

1. Welge, H. J.: "A Simplified Method for Computing Oil Recovery by Gas or Water Drive," *Trans.* AIME, (1952), 195, 91.

AUTHOR'S REPLY TO MR. WELGE

Welge has poined out clearly the difficulty of applying material-balance procedures in calculating the performance of low-pressure, dispersed gas injection operations. There can be no argument that even with the most favorable assumptions of K_o/K_w and with cumulative gas cycling in excess of normal expectations, the calculated oil recovery will be considerably less than the 72.5 per cent recovery realized from this project to Jan. 1, 1951. There probably are at least two reasons for the unusually high recovery from this reservoir, the effects of which would be difficult or impossible to calculate by known methods:

1. The operator did not use the same injection wells for the entire operation, and exercised considerable control over producing GOR by changing the locations of injection wells whenever well performance indicated excessive bypassing. Fifty-six wells were used for injection, not over 29 of which were in use simultaneously. This procedure resulted in frequent shifting of the fluid movement patterns in the reservoir and undoubtedly increased the ultimate recovery. The writer knows of no satisfactory procedure for calculating the effect of this practice.
2. Vertical movement of oil across the bedding planes of the reservoir rock by gravity drainage tended to maintain a relatively high oil saturation, and hence a favorable K_g/K_o ratio, in the lower sections of the reservoir. As pointed out by Welge, this condition has aggravated the tendency for high producing GOR, but at the same time it has resulted in increased oil recovery. As may be seen from the performance charts for the various battery areas, operating GOR's have been quite high for the last several years of reported history. ★ ★ ★

LABORATORY DETERMINATION OF RELATIVE PERMEABILITY

J. G. RICHARDSON, J. K. KERVER, JUNIOR MEMBERS AIME, J. A. HAFFORD AND J. S. OSOBA, HUMBLE OIL AND REFINING CO., HOUSTON, TEX.

(Published as T.P. 3375, Page 187)

DISCUSSION

By Forrest F. Craig, Jr., Stanolind Oil and Gas Co., Tulsa, Okla., Member AIME

The authors are to be commended for their experimental verification of the influence of boundary end effect as predicted from the equations of fluid flow. Research workers have long recognized the need for this comparison of the experimental and theoretical saturation gradients due to boundary effect. It is also satisfying to note the authors' work comparing the experimental and theoretical effects of gas expansion. Their careful and ingenious experimental work is a high point of the paper.

The comparison of the various methods of laboratory determination of relative permeabilities is most valuable. It has been found, however, in the Stanolind Oil and Gas Co. Research Laboratory, that the calculation of gas-oil relative permeability ratios from gas drives, using one-half the effluent oil rate and specifying the k_e/k_a values, thus obtained, at the average saturation can be greatly in error.[1] Gas drives on more than 20 different sandstone and limestone core samples have shown that the gas-oil relative permeability ratios, so calculated, vary from the true values, as calculated by the recently proposed method,[2] by from 10 to over 800 per cent. To date no rigorous method of calculating individual gas and oil relative permeabilities from external gas drive data has been devised.

REFERENCES

1. Craig, F. F., Jr.: "Errors in Calculation of Gas Injection Performance from Laboratory Data," *Trans.* AIME, (1952) **195**, TN 126.

2. Welge, H.: "A Simplified Method of Computing Oil Recovery by Gas or Water Drive," *Trans.* AIME, (1952) **195**, 91.

AUTHORS' REPLY TO MR. CRAIG

The comments of Craig are appreciated and his point concerning the calculation of relative permeabilities from gas-drive experimental data is well taken. The factor of one-half used in calculating the relative permeability to oil from gas-drive data is an empirical correlation number which for many samples brings the relative permeabilities to oil determined from gas-drive experiments into agreement with those determined by steady-state methods. In comparing results obtained on 60 core samples by both steady-state and gas-drive methods, this correlation factor brought gas-drive permeabilities to oil into exact agreement with those determined by the steady-state method in 60 per cent of the cases. Of those which disagreed to a varying extent, about one-half were high and the other half were low. Many of the samples on which disagreement was obtained were heterogeneous in character, for example, vugular limestones or sandstones with shale streaks.

On the other hand, for a limited number of cases, K_o/K_a-saturation relations did not agree with those determined by steady-state methods. Since the Welge method involves a number of simplifying assumptions, it was felt that perhaps these assumptions were not valid for the particular runs that were made. It is to be hoped that further work will yield a better understanding of the utility or limitation of each of the calculation procedures for handling the laboratory gas-drive data.

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ELECTRICAL RESISTIVITY MEASUREMENTS ON RESERVOIR ROCK SAMPLES BY THE TWO-ELECTRODE AND FOUR-ELECTRODE METHODS

C. F. RUST, MAGNOLIA PETROLEUM CO., DALLAS, TEX.

(Published as T.P. 3397, Page 217)

DISCUSSION

By H. F. Dunlap, The Atlantic Refining Co., Dallas, Tex., Member AIME

We believe that the conclusions stated in this paper are too sweeping. Our own experience indicates that (1) two-electrode resistivity measurements are in general not as reliable as four-electrode measurements, and (2) use of non-equilibrium brine saturations in determining the saturation exponent n may, in some cases, lead to quite erroneous determinations. While we do not contend that the data reported are incorrect, the conclusions drawn from them are too general.

The paper gives the impression that the two-electrode and four-electrode methods are equally reliable. Actually, the data given in Table I show significant differences between two-electrode measurements obtained using the painted end electrode technique and two-electrode measurements made without using painted ends. Table I shows that of 13 measurements using cores with painted ends, 11 showed a lower resistivity than was recorded by the four-electrode technique on these cores, while of the 47 cores measured without painting the ends, 29 cores showed a *higher* resistivity using the two-electrode instead of the four-electrode method. While the differences in resistivity referred to here are in general small, the largest being about 17 per cent, these results at least suggest that (1) where painted end electrodes are not used, there is a tendency for the two-electrode method to give a value of resistivity which is somewhat too high, and (2) where painted end electrodes are used, the resistivity values obtained with the two-electrode method are somewhat too low (possibly due to penetration of the rock by the conducting paint?). While it is not our contention that careful work cannot yield reliable resistivity measurements using the two-electrode method, it has been our experience that four-electrode measurements are just as easy to make and are fundamentally much more reliable. The reliability of measurements made with a two-electrode method might be considered analogous to the reliability of voltage measurements made with a low resistance voltmeter.

while the four-electrode method might be considered analogous to voltage measurements made with a potentiometer.

We also wish to take exception to the second conclusion offered by Rust, in which he states that in determining the saturation exponent n, resistivity values at both equilibrium and non-equilibrium brine saturations may be used. Fig. A shows an experiment, given in a previous paper by Dunlap, *et al.*,[1] on the relation of resistivity to brine saturation in reservoir rocks, which demonstrates that very erroneous answers for n can be obtained if non-equilibrium values are used. We have made many other runs showing this effect, particularly on unconsolidated samples.

We are also surprised at the excellent reproduciblity of the resistivity *vs* average saturation plots shown in Fig. 10 which were obtained for the three-in. long core equipped with multiple potential electrodes shown in Fig. 9. We have also performed many experiments exactly like this, and we find that, in general, when long cores are desaturated in this way, water is usually trapped in the upper sections so that resistivity measurements made in the upper section of the core are quite different from those made closer to the porous diaphragm, even after many days have elapsed since the desaturating pressure was first applied. Fig. B shows one experiment which illustrates this effect occurring in a rather permeable oolitic limestone. This core was about one-in. high and seven-eighths-in. in diameter, and after 10 days there was still a pronounced resistivity gradient, indicating that water has been trapped at the top of the core. In another experiment, a Strawn sandstone core 10-in. long, 1 in. in diameter, permeability of about 500 md, was mounted vertically on a capillary plate and desaturated for two months with a constant pressure of 10 psi of naphtha. At the end of this time the core was broken up and analyzed one section at a time. It was found that a pronounced saturation gradient existed, with the portion of the core closest to the porous disk being essentially at connate water (about 30 per cent water), while the top portion of the core still contained 50 per cent water. Resistivity measurements were not made on this last experiment, but the lower portion would undoubtedly have shown a higher resistivity than the upper portion.

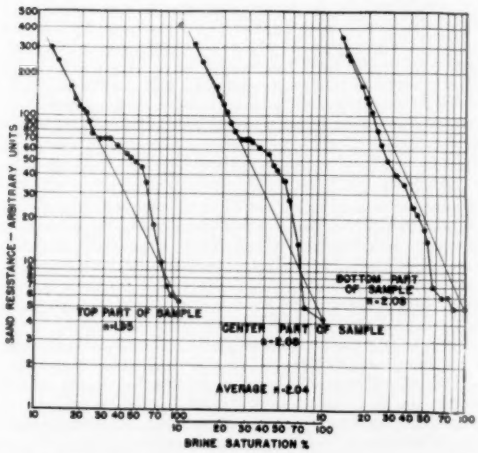

FIG. A — RESISTANCE AS A FUNCTION OF BRINE SATURATION FOR A CLEAN UNCONSOLIDATED SAND. POROSITY, 37 PER CENT; DISPLACING MEDIUM, N_2; CONSTANT DISPLACEMENT PRESSURE, 2 PSI.

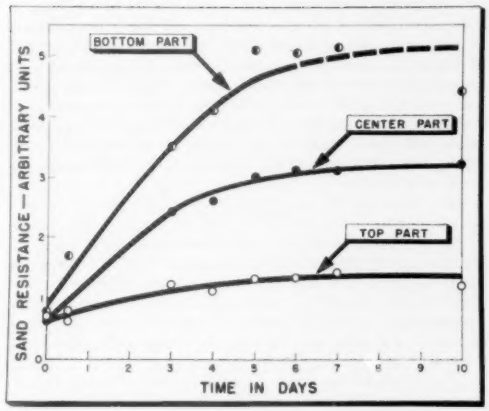

FIG. B — RESISTANCE AS A FUNCTION OF TIME. Ka, 1129 MD; P, 19.7 PER CENT.

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1. Dunlap, H. F., Bilhartz, H. L., Shuler, E., and Bailey, C. R.: "The Relation Between Electrical Resistivity and Brine Saturation in Reservoir Rocks," *Trans.* AIME, (1949), **186**, 259.

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AUTHOR'S REPLY TO MR. DUNLAP

The conclusions drawn are based entirely on the results of the measurements presented in this paper. On the basis of these measurements one must conclude that, provided proper techniques are employed, either the two-electrode or four-electrode method will yield reliable resistivity values. The writer is aware of the fact that comparisons of resistivity measurements made by different laboratories on the same core samples often leaves much to be desired, not only when the comparison is made between two different methods, but between measurements utilizing the same method.

These laboratories have employed the four-electrode method in electrical resistivity measurements almost exclusively for several years. Other laboratories in the industry, particularly commercial laboratories, prefer, for reasons of their own, the two-electrode method. It was not the intent of this writer to suggest the substitution of one method for the other, but only to compare and evaluate differences between them. A comparison of the two methods seemed desirable because often the size of core samples is such that the four-electrode method cannot be applied and one is forced to employ a two-electrode system. As Dunlap admits, the differences between the two types of measurement are small. He points out that 29 of the unpainted samples show higher resistivities when the two-electrode method is used; for seventeen samples, however, the two electrode method yields lower values, while for one sample the measurements are the same. The writer does not accept the suggestion that two-electrode measurements made on painted samples are lower than four-electrode measurements. Generally, two-electrode measurements made on the same samples, with and without the use of silver paint, agree well within the experimental errors permitted in resistivity measurements. There appears to be no reason, therefore, to segregate the painted from the unpainted samples. As this writer has pointed

out, the painting technique of Morgan, Wyllie, and Fulton[1] is a novel one and most satisfactory, particularly if resistivity measurements are made over long intervals of time. However, the use of silver paint is not always desirable, particularly if the samples are to be subjected to other tests such as chemical, or *X*-ray analyses following the resistivity measurements.

Dunlap's analogy between the two methods of resistivity measurement to voltage measurements with a low resistance voltmeter and a potentiometer appears to be irrelevant to the problem at hand.

With regard to the use of non-equilibrium brine saturations in determining the saturation exponent *n* the writer again wishes to emphasize that the conclusions drawn are based on his own experimental results. He is aware of the fact that this topic has been the subject of considerable debate among workers in this field in the past and it is well to recognize the experimental difficulties associated with this problem and to be aware of erroneous results due to faulty techniques. It is apparent that there are differences between the work of Dunlap *et al*[2] and that of the writer. These differences pertain to both the type of sample compared as well as difference in measuring technique and procedures. For example, the results shown in Fig. A of the above discussion were obtained on an "unconsolidated" sample, while those presented in this paper are for consolidated samples only. The displacing medium for the former was nitrogen, for the results presented in this paper a liquid (isooctane) was used. It is perhaps significant, also, that in all cases the pressure was increased stepwise, while for many of the results shown by Dunlap *et al* the final desaturation pressure is applied immediately. The author has measured saturation exponents for scores of samples, but in no case have anomalies of the type described in this discussion been observed.

Finally, Dunlap expresses surprise at the excellent reproducibility in the case of the long core sample obtained from a *homogeneous, clean* Woodbine outcrop and contrasts these results with those obtained by him on a limestone sample. At these laboratories our experience with studies of long samples is limited to this single case. The measurements have since been repeated, inverting the core sample, and finally by breaking up the sample into three samples of inch length yielding the same results. No resistivity gradient could be detected.

It is this writer's opinion that electrical resistivity measurements on reservoir rocks can be made successfully only if precautions are taken all along the line from the proper extraction of both salt and oil from the sample to the determination of its degree of saturation. These precautions coupled with those mentioned in connection of measuring techniques discussed in this paper will generally yield reliable and reproducible results.

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USE OF ACTIVATED CHARCOAL IN CEMENT TO COMBAT EFFECTS OF CONTAMINATION BY DRILLING MUDS

B. E. MORGAN, JUNIOR MEMBER AIME, AND G. K. DUMBAULD, MEMBER AIME, HUMBLE OIL AND REFINING CO., HOUSTON, TEX.

(Published as T.P. 3396, Page 225)

DISCUSSION

By Francis M. Anderson, Halliburton Oil Well Cementing Co., Duncan, Okla.

The paper just presented is quite timely in this day of specialty drilling fluids containing large quantities of treating chemicals, almost all of which are highly detrimental to the setting of portland cement.

The advent of these highly treated drilling fluids has been followed by a marked increase in trouble with cement. Cement placed in these wells has taken an unusually long time to set, or reportedly has not set at all. This has been particularly true in wells where lime base mud has been used, as these muds are necessarily treated with large concentrations of quebracho or lignin compounds, or both, and in many cases contain such organic colloids as starch, sodium carboxymethylcellulose, natural gums, etc., all of which are known to affect cement adversely. To date, the effect of these drilling muds on cement has been combatted primarily by improving the mechanical techniques of performing the cementing job. Such devices as both bottom and top plugs used inside the casing, wall cleaning devices used in conjunction with pipe movement, and buffer washes used ahead of the cement, have been employed with more or less success in different areas.

The work of Morgan and Dumbauld appears to be the first successful use of an additive which can be blended with a cement to successfully counteract the effect of these muds. The additive they have chosen apparently acts by adsorbing the offending treating chemical rather than counteracting it chemically, thus it has no effect on the setting of the cement itself. For this reason, it appears ideal for use in cements containing no chemical retarders. It is unfortunate that the retarders used in most slow setting oil well cements are very similar to the compounds used for treating drilling muds and are thus subject to being adsorbed by charcoal in the same manner. This is especially true since highly treated muds are used extensively in the deeper wells where slow setting cements are required.

A great amount of trouble has been encountered in obtaining successful plug back jobs in open hole, for it is on these jobs that the cement has the greatest chance of becoming contaminated with mud. The authors appear to have opened a new approach to this longstanding problem. The use of activated charcoal in this one application may well pay big dividends if it will help eliminate failures.

The use of activated charcoal could be an important factor in obtaining successful squeeze jobs when squeezing formations into which highly treated muds have been lost ahead of the cement. In fact, any cementing operation where trouble is encountered because of contamination with such drilling muds should be improved by the use of this additive.

The authors have done a creditable piece of work and are to be commended for the manner in which they have presented it.

AUTHORS' REPLY TO MR. ANDERSON

Anderson has mentioned the increase in trouble with cement since the advent of muds heavily treated with quebracho, lignin materials, starches, etc., particularly in operations such as the setting of a plug in open hole. It is felt that the use of activated charcoal in cement is a practical way of reducing the seriousness of this problem.

Anderson has pointed out that the chemicals commonly employed for mud treatment are similar in composition and behavior to the chemicals used to retard the set of many slow-set cements; therefore, activated charcoal is likely to adsorb the retarders and shorten the pumpability of slow-set cements. Data on these points which are presented and discussed in the paper may be sumarized as follows:

1. Activated charcoal does shorten the pumpability of some slow-set cements containing organic-type retarders; hence, activated charcoal should not be added to slow-set cements containing retarders without first checking the effect upon the pumpability of the particular cement. This effect is apparently similar to that encountered when high percentages of bentonite are added to this type of slow-set cements.

2. Activated charcoal does not change the pumpability of normal portland cements and slow-set cements which contain no organic-type retarders; therefore, for moderate temperature jobs, satisfactory cementing compositions containing activated charcoal may be prepared by the use of any normal portland cement .For high temperature jobs, satisfactory cementing compositions containing activated charcoal may be prepared by the selection of a straight, unretarded slow-set cement.

3. The effect of the contamination of cement slurries by treated muds is more pronounced at low temperatures than at high temperatures. Contamination may be more serious, therefore, in wells where heavily-treated muds are encountered at moderate depths rather than in deep, high temperature wells.

Appreciation is expressed to Anderson for his thoughtful discussion of our paper.

DISCUSSION

By S. H. Davis, Atlantic Refining Co., Dallas, Tex.

I would like to ask the author if any attempt has been made to separate the effect of the several additives, particularly the caustic and quebracho, if any setting time tests were made using only one or the other to see which is doing the major part of the damage.

AUTHORS' REPLY TO MR. DAVIS

Our laboratory investigation did not include tests of caustic and quebracho separately. Data on the specific effect of many chemicals, including caustic and quebracho, may be found in one of the references cited, "The Effects of Drilling-Mud Additives on Oil-Well Cements," API *Bulletin D-4*, (Sept. 1951). This publication may be obtained from American Petroleum Institute, Production Division, Dallas, Tex. ★ ★ ★

X-RAY SHADOWGRAPH STUDIES OF AREAL SWEEPOUT EFFICIENCIES

R. L. SLOBOD AND B. H. CAUDLE, THE ATLANTIC REFINING CO., DALLAS, TEX.

(Published as T.P. 3440, Page 265)

DISCUSSION

By T. M. Geffen and R. E. Gladfelter, Stanolind Oil and Gas Co., Tulsa, Okla.

We have followed the lead of The Atlantic Refining Co. in studying the areal sweepout of oil by pattern flooding using the *X*-ray shadowgraph technique, and have made studies on five-spot pattern flooding similar to those in this paper. We are in general agreement with their curve of mobility ratio *vs* areal sweepout efficiency for a five-spot pattern flood; however, there is one subject that was not fully discussed which is of considerable importance. This subject is the effect of scaling the fluid and rock characteristics and well bore when using small models to represent a large reservoir. Capillarity is one of the important characteristics to be considered in studying water flooding with small models. In the reservoir, considering the rates of advance of the water in pattern floods and the magnitude of the capillary forces, it is reasonable to expect that the portion of the reservoir in which water is advancing or being held back entirely by capillarity is small compared to the area under flood. In the model, with the same fluids and rock material, this zone, due to capillarity, can be relatively large compared to the model, resulting in a sweep efficiency different from that which would take place in the reservoir. The authors have handled this scaling problem by eliminating the effects of capillarity with the use of miscible fluids. This approach also creates a problem of a similar nature. The miscible fluids mix and form a zone that has the same detrimental effect as does capillarity. This mixing, or fingering, is most severe in the laboratory tests conducted with fluids in the low mobility ratio range. In the paper, the fingering nature of the flood patterns is attributed to rock characteristics. In addition to this, it is also due to the nature of the fluids. As a solution to this problem of scaling, a one-quarter section of a five-spot flood pattern, as shown in Fig. A, was flooded using water to displace oil from a consolidated sandstone (Torpedo) model containing connate water at a mobility ratio of 0.24. The oil and water were stabilized with a mutually soluble alcohol to appreciably reduce the interfacial tension which in turn reduced, proportionately, the effect of capillarity. The capillarity has not been scaled precisely, but appears to approach what would happen in the reservoir because the boundary between the oil and water is comparatively sharp and smooth and the pattern at breakthrough is readily outlined. Using this same model and using miscible fluids at a mobility ratio of 0.25, a fingering pattern was obtained as

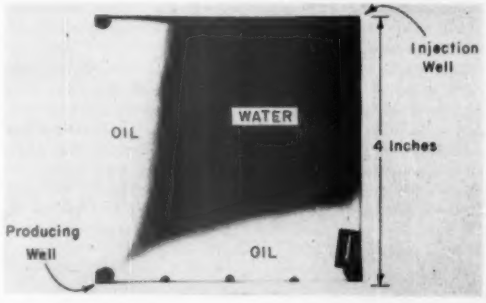

FIG. A — FIVE SPOT PATTERN FLOOD AT WATER BREAKTHROUGH FOR MOBILITY RATIO = 0.24, PATTERN EFFICIENCY = 60.7 PER CENT AND LOW INTERFACIAL TENSION.

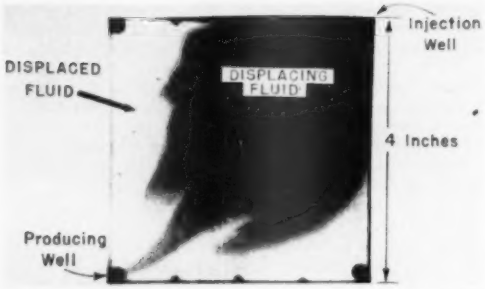

FIG. B — FIVE-SPOT PATTERN FLOOD AT BREAKTHROUGH FOR MOBILITY RATIO = 0.25, USING MISCIBLE FLUIDS.

shown by Fig. B. Fig. B is evidence of the difficulty encountered in obtaining a measure of pattern efficiency at this low mobility ratio. The use of low interfacial tension fluids may offer a better means of more precisely interpreting areal sweepout efficiency of pattern floods on models, inasmuch as the demarcation between displaced and displacing fluids is sharper.

A series of floods using the alcohol treated oil and water were made at various mobility ratios. The results are in general agreement with areal sweepout efficiency for a five-spot given in the paper. The only significant deviation is for mobility ratios of less than one, where the results ranged up to five per cent areal sweepout efficiency above the correlation of Fig. 4 in the paper. Although Fig. 4 may not be precise over the entire range of mobility ratios, it should be satisfactory for engineering purposes for field application considering the areal variations in permeability possible in actual reservoirs.

The discrepancy between results by the potentiometric model and shadowgraph techniques for a line drive may, in addition to the author's explanation, be attributed to mixing effects and the accompanying difficulties in interpreting the results.

The effect of scaling the well bore diameter was also investigated. A 4 in. x 4 in. x $3\frac{1}{4}$ in. model and a 24 in. x 24 in. x $3\frac{1}{4}$ in. model were flooded corner to corner with the same fluids in the form of a quarter section of a five-spot. The well bores were $\frac{1}{8}$-in. diameter in both models, which simulates 15.6 ft and 2.6 ft well bores, respectively, for the reservoir with the wells 500 ft apart. The area sweepout efficiency, at a mobility ratio of 0.92 was approximately 69 per cent in both cases. This agreement and the fact that the larger model was scaled to approximate field conditions, indicates that the smaller model, as well as the one the authors used, is sufficiently scaled for all practical purposes for a mobility ratio of one or greater. For mobility ratios less than 1.0, where the cusping tendency becomes greater, the scaling of the well bore may be more important when using the smaller model. ★ ★ ★

THE CALCULATION OF PRESSURE DROP IN THE FLOW OF NATURAL GAS THROUGH PIPE

FRED H. POETTMANN, PHILLIPS PETROLEUM CO., BARTLESVILLE, OKLA., JUNIOR MEMBER AIME

(Published as T.P. 3217, Page 317, Vol. 192)

DISCUSSION

By R. V. Smith, U. S. Bureau of Mines, Bartlesville, Okla.

An equation, such as Poettmann has presented,* for computing the pressure drop for the flow of natural gas through pipe, must evaluate adequately the available energy derived from the flow process and the energy used in overcoming the friction between the moving fluid and the pipe wall. The available energy is determined by the flow process that follows a path fixed by conditions of temperature, compressibility, and phase changes of the fluid during this process. The energy consumed in overcoming friction is determined by the friction coefficient, which is the dimensionless correlating function using Poettmann's nomenclature.

In a flowing gas well, the decrease in pressure as the fluid moves from the bottom to the top of the well allows the fluid to expand while the decrease in temperature usually found in gas wells allows the fluid to contract. In low-pressure gas wells with relatively low reservoir temperatures, the flow process is principally expansion; but in wells producing from high-temperature reservoirs at relatively high pressures, the temperature decrease may cause a contraction in the volume of the fluid that is greater than the expansion caused by the decrease in pressure.

In order to determine the available energy from the flow process, the integral, $\int v dp$, must be evaluated between the proper limits of pressure over the actual path of the flow process. Poettmann has approximated this evaluation by assuming that the flow process is always an expansion at an average temperature and by assuming that compressibility of the fluid changes only with pressure. However, his treatment of compressibility is an important step toward solution of the problem of calculating subsurface pressures in flowing gas wells, and the values of $\int_{0.2}^{P_s} \frac{Z}{P_s} dP_s$, given in Table I, makes his method especially usable.

Friction coefficients, based on an absolute roughness of 0.0006 in. for the pipe used in gas wells, probably are more representative of conditions found in gas wells than are obtainable using other published values. However, it must be pointed out that an average absolute roughness value cannot apply equally to all gas wells without consideration of pipe age and corrosive conditions to which the pipe may have been exposed.

With reference to Equation (15) in the paper, the author has assumed that $[\int v dl]^2$ may be used in place of $\int v^2 dl$ or their equivalents, as is usually done in the development of flow equations. As the two expressions are not identical, the author should explore the significance of such an assumption and show the limits wherein the assumption may be used without appreciable error.

In presenting a method for calculating subsurface pressures in flowing gas wells that provides for the variation of compressibility with pressure, Poettmann has made an important contribution toward solving a complicated problem. In addition, he is to be commended for presenting his method in a convenient, usable form . ★ ★ ★

*This paper was published in Vol. 192 (1951) of AIME *Transactions*, rather than in the present volume as are the other papers here discussed.

The Drift of Things

. . . as followed by **EDWARD H. ROBIE**
Secretary AIME

The Election

Political matters are a subject on which the AIME, as a professional society, rightly takes no official position. Now that the presidential election is over, however, comment on its outcome can hardly be construed as offensive to the membership. To any one who has attended any kind of an AIME meeting, in any part of the country, it must have been evident that an enormous majority of AIME members wanted Eisenhower to win. The feeling was so general that a Democrat had to keep his political leanings to himself until behind the curtain of the voting machine or the ballot box. But in spite of the Eisenhower "landslide," it appears that only about 55 out of every 100 voters gave him their nod at the polls. This proves that AIME members, as might be expected, are anything but an index of the political leanings of the country. It seems likely that independent business men and salaried employes largely voted one way, and wage earners the other.

As this is written, we have reports from only 97.3 per cent of the precincts, but if the other 2.7 per cent follow the same ratio, the total popular vote for the leading candidates in recent elections will look like this:

Year	Total Vote in 1000's	Per Cent to Winner
1952	61,400	55.3
1948	46,076	52.3
1944	47,609	53.8
1940	49,548	55.0
1936	44,157	62.2
1932	38,585	59.3
1928	36,408	58.6

It thus appears that out of every 100 persons who voted in the 1948 election 7.6 persons changed their party vote in 1952. That statement, of course, is not entirely accurate, for 15 million more people voted for the leading candidates in 1952 than in 1948, and maybe most of these did not vote at all in 1948.

It is anybody's guess what influenced this comparatively small group of independent voters but our guess is that the main reasons were these: (1) Eisenhower's personal popularity and the fact that his name has long been a household word as a likable person of excellent repute. (2) Continuing reports from Washington in recent years that money was being wasted, of scandals in the administration, of Communist infiltration. (3) Desire to uphold the two-party system, and to turn out *any* crowd that had been in the saddle for 20 years, Republican or Democrats. (4) A feeling that we should not have been dragged into the Korean war, but now that we are in a military man is more likely to get us out than a politician.

The pollsters took a licking almost as bad as that which broke the back of *The Literary Digest* in 1936 when it predicted that Landon would win over Roosevelt. Political sampling is evidently far less scientific than mine or metallurgical sampling.

Oil Boom on Musical Stage

Michel T. Halbouty, consulting geologist and well-known petroleum engineer, jointly with James A. Clark, oil editor of *The Houston Press*, recently published a book entitled "Spindletop," based on what happened around Beaumont, Tex., after the famous gusher started to spout its liquid wealth back in 1901. Plans are now being made to make a musical show out of the book. Mining has been the subject of several plays and musical productions but we do not recall the petroleum industry being given similar treatment. With plenty of Texas oil money no doubt available, the production should be elaborate. We trust it will duplicate on the stage the success of "Louisiana Story" on the screen.

More Engineers Coming

Our personal contacts with educators have been scattered in the last two months or so, but it seems certain that many more young men entered engineering schools last fall than for some time. Dean Potter, of Purdue, told us that his freshman engineering class is more than half again as large as in 1951. We suspect that the mineral field has not been quite so enticing as the electrical, for instance, but undoubtedly the number of graduates in mineral engineering in 1956 will show an increase. For this upward trend, the Engineering Manpower Commission of Engineers Joint Council is undoubtedly more responsible than any other agency. Engineers will continue to be in short supply for some years unless a serious depression occurs. They are more and more in demand for managerial jobs. A year ago it was estimated that jobs were waiting for 80,000 more engineers than were available. Probably the current deficiency is less than half this.

EJC has been less successful in its efforts to induce the Army to utilize its engineering draftees in ways to take advantage of their training and experience. Instance after instance has been cited wherein well-trained engineers, many with practical experience, have been given menial work or have been assigned technological duties that any high school graduate could perform.

Deepest Mine

It has been some years since we reported on the deepest mine in the world. Progress in this respect in mining has by no means equaled that in oil, which has wells close to four miles deep. Several mines in South Africa and India are around 9,000 ft deep but we understand the deepest of all is that of Crown Mines Limited, whose T.2 Winze last spring reached a depth of 9,876 ft below surface. At that depth the virgin rock temperature is 115°F. East Rand Proprietary is deepening its Central Subvertical Shaft which on Aug. 21 had reached 9,521 ft.

Signing Off

For 20 years we have been responsible for contributions to this department. For the last four years, since our responsibilities with the AIME broadened and increased, the job has been indifferently done, chiefly, we hope, because of lack of time. At least we are not satisfied with the product. Decreasing the stint from two pages to one unfortunately did not improve matters. We are, therefore, turning the department over to the editors of the three journals who, perhaps, may allow us to contribute a guest paragraph or two when inspiration strikes. In the meantime, we hope to write a few items for the AIME news department each month.

We have taken a great deal of pleasure in writing material of this kind, particularly the nonsense. The lighter stuff has brought us many friendly letters. It is time to stop while our reputation is still reasonably good. ★ ★ ★

Petroleum Branch Affairs . . .

as interpreted by
E. J. KENNEDY, Assistant Secretary, AIME, and
BEKY YODER, Assistant Secretary, Petroleum Branch, AIME

For the purpose of acquainting new members, and possibly old ones, with the manner in which a paper is selected for publication in JOURNAL OF PETROLEUM TECHNOLOGY, we should like to follow the route of a paper from its receipt in the Branch office to its final disposition.

The Petroleum Branch Publications Committee, consisting of six to ten members, composes a forum for the consideration and disposition of all papers submitted for publication. This committee is appointed for one year, and is seated in a different general area each two years.

When a manuscript is submitted to the Petroleum Branch it is assigned a "G" number, which is the Institute symbol for "petroleum," for the purpose of preliminary identification. This symbol was established years ago by assigning letters to various Divisions in alphabetical order. A copy of the paper is sent to the chairman of the Publications Committee who (with the help of the committee) suggests three to five "readers" carefully selected for their qualification to evaluate the particular subject matter. The Branch office sends a copy of the manuscript to each of the readers along with a letter requesting confidential appraisal of the paper. In reviewing the paper, the reader is requested to base his evaluation on these primary technical paper standards: (1) Does it make a substantial contribution to the existing knowledge of the subject, and (2) if it is a review type paper, is it one which will be valuable in the permanent literature. Composition and grammar should be considered also. In addition, the following specific questions are asked: (1) What prior publication of the material is known, (2) Does the reader recommend publication as a technical paper? If not, in any other form? (3) Indicate what parts of the paper should be condensed, if any. (4) Indicate any illustrations that could be omitted. The replies are termed "reader comments." Copies of all comments are sent to each member of the Publications Committee. The committee meets periodically to review the comments and approve for publication or decline papers according to the majority opinion of the readers and the committee. If there is an extreme difference in the comments or doubt about acceptance, additional reviews are solicited. Some papers are accepted for publication as written, but most of the papers are improved by revisions suggested by the readers. Under the direction of the Publications Committee the Branch office sends unidentified copies of constructive reader comments to the author for his consideration in revising the paper to make it more acceptable for publication. Both readers and author can greatly facilitate the processing of a paper by prompt action.

Visit the new offices of the Petroleum Branch, AIME, now located at 300 Fidelity Union Bldg., junction of Bryan, Pacific and Akard streets, Dallas, Tex.

If the paper is approved as a technical paper the Branch office requests a Technical Publications (T.P.) number from the AIME New York office and the paper is included in the *Transactions* section of the JOURNAL OF PETROLEUM TECHNOLOGY. T.P. numbers have been assigned consecutively to all Institute papers for years, and we are now in the 3300 series. Additional copies of the *Transactions* section are printed each month as the magazine is printed and at the end of the year are bound into a hard bound *Transactions* volume, so that each member receives all the papers published through the magazine and also has the opportunity of purchasing a bound volume, a more satisfactory permanent reference, if he wishes.

Each paper is first considered as a technical paper. However, if it does not meet the necessary requirements, but is of interest to the membership, it is considered for publication as an "article" in the front section of the magazine. This section is intended to be more general in nature and to have a broader appeal than the technical or *Transactions* section.

Technical Notes are numbered separately from papers, and are identified by the letters T.N. preceding the number. A Note is usually reviewed by only one or two readers and, if approved, is published in the magazine when space will permit. At the end of the year the Publications Committee selects the notes published during the year to be included in the annual *Transactions* volume.

The Institute Technical Publications Committee, seated in New York, approves all papers published by the Institute. However, it has been found desirable to delegate the selection of petroleum papers to the Petroleum Branch Publications Committee, actually an auxiliary committee of the T.P.C., and Institute Committee approval is automatic. A copy of each paper is sent to the Institute staff in New York, and at the end of the year a summary of the disposition of all the papers handled during that year is sent to New York.

The majority of the papers are received prior to and for the purpose of presentation at the Fall Meetings. However, submission of papers is invited at any time, as is discussion of any paper which appears in the magazine. ★ ★ ★

Petroleum Section Conference Meets

Raymond E. Howard, chairman of the Permian Basin Section, was elected chairman of the Petroleum Section Conference at its first meeting Oct. 1. Norman Lamont, faculty member at Texas Technological College in Lubbock was elected the first secretary-treasurer of the conference.

Composed of representatives of all the Petroleum Local Sections of the Institute, the conference was established to discuss Section problems and Branch business and to advise the executive committee of membership opinion on various issues.

At its first meeting, the conference voted against establishing a revolving fund to subsidize Petroleum Branch Fall Meetings, as proposed by the Oklahoma City Section. Acting on the suggestion of the conference, the executive committee subsequently voted to thank the Section but to decline its offer of $1,000 for such a fund, and to return the money to the Section.

In other action, the conference suggested that the plan for revising Petroleum Branch Fall Meetings be tabled for further consideration. It also discussed the proposals for changing the name of the Institute and indicated a preference that the matter be dropped. ★ ★ ★

J. K. WRIGHT has opened consulting offices at 1101 Standard Life Bldg., Jackson, Miss., specializing in evaluation, advice on exploratory ventures and appraisals of producing properties. Wright worked with various companies in Oklahoma and Arkansas from 1936 to 1945, when he became chief engineer for the Mississippi Oil and Gas Engineering Committee. He became director in 1946, and when this organizaton was inactivated in 1949 he joined the Mississippi State Oil and Gas Board as chief engineer. He holds active membership in a number of associations in the oil and gas industry, and was instrumental in founding the Mississippi Sub-Section of the AIME.

A. N. Holden to Receive Award for Iron Paper

A. N. Holden, research assistant at the Knolls Atomic Power Laboratory of the General Electric Co., Schenectady, has been chosen to receive the Rossiter W. Raymond Award for the current year. This award is given for the best paper published by a member of the Institute under 33 years of age. Holden's paper was entitled "Dislocation Collision and the Yield Point of Iron." It was published in the JOURNAL OF METALS last February. ★ ★ ★

Science Association To Meet Dec. 27-30

The annual meeting of the American Association for the Advancement of Science will be held in St. Louis, Dec. 27-30, 1952. Section M - Engineering is to have a general symposium on disaster recovery and a conference on scientific man power. Other subjects include "Isotopes in Industry," "Health Hazards and Health Protection," "Methodology in Engineering Research," and a symposium on "Hearing and Speech Aids." ★ ★ ★

Visit the new offices of the Petroleum Branch, AIME, now located at 800 Fidelity Union Bldg., junction of Bryan, Pacific and Akard streets, Dallas, Tex.

H. JAMES RAMSEY has joined the Magnolia Petroleum Co. in Salem, Ill., as petroleum engineer.

+

GEORGE F. CLEMENTS, JR., has rejoined the Empire Trust Co. in New York, N. Y., in the oil and natural gas department. He was recently discharged from the Air Force.

+

SHANNON L. MATHENY, JR., petroleum engineer trainee with the Continental Oil Co., is now at Ponca City, Okla.

+

JOHN J. MCKETTA, JR., has been awarded a plaque for the best paper published during 1951 by a member of the South Texas Section of the American Institute of Chemical Engineers. The paper, entitled "Vapor-Liquid Equilibrium Constants in the Methane-Water and Ethane-Water Systems," was published in the AIME *Petroleum Transactions*, Vol. 192. A staff member of the Department of Chemical Engineering at the University of Texas until June of this year, McKetta is now editorial director for *Petroleum Refiner*, published in Houston, Tex.

G. TIMMINS ALEXANDER, JR., is now employed as a petroleum engineer with the Southern Production Co., Baton Rouge, La.

+

JOHN O. NIGRA has resigned his position as research geologist with the Arabian American Oil Co. in New York. He is now available for consulting work, located at 851 N. Madison Ave., Los Angeles 29, Calif.

+

W. L. CHILDS, JR., has been appointed sales manager of the oil tools division of Reed Roller Bit Co. in Houston, Tex. He has been with the company since his graduation from the University of Texas in 1939. During World War II, he served with the U. S. Air Force, attaining the rank of lieutenant colonel. After his release from the service in 1946, he became sales engineer for the company, and in 1948 was made manager of the south central sales division in Shreveport. He managed the Canadian sales division for a short time, and then returned to Houston in 1949 as manager of the Gulf Coast sales division.

Advertising Sales-Director Appointed For Journal of Petroleum Technology

Richard C. Wipperman, widely known publisher's representative and former Southwestern manager for McDonald-Thompson Co., has been appointed to direct the advertising sales for the JOURNAL OF PETROLEUM TECHNOLOGY.

RICHARD C. WIPPERMAN

Wipperman, whose appointment will become effective Jan. 1, 1953, will be headquartered at the Petroleum Branch offices in the new location of 800 Fidelity Union Bldg., Dallas, Tex. He will direct advertising sales in the Southwest and on the West Coast, this territory including the states of Louisiana, Arkansas, Oklahoma, Texas, New Mexico, Colorado, Arizona, Utah, Nevada and California. Advertising sales in the East are now being directed by Lewis V. Hohl of New York, N. Y.

Wipperman has had some 25 years' experience in advertising sales work in the petroleum publications, all in the Mid-Continent and West Coast areas. For the past two years, he has handled sales for the JOURNAL OF PETROLEUM TECHNOLOGY on a publisher's representative basis. In 1950, Wipperman moved to Dallas where he began his work for PETROLEUM TECHNOLOGY as area manager for McDonald-Thompson. Prior to that time his offices were in Los Angeles. ★ ★ ★

Nominating Committee Announced For 1954 Institute Officers

As provided in Article IX, Section 2, of the AIME Bylaws, the names and addresses of the Nominating Committee for Institute officers in 1954 are given below. In each case, the name in parenthesis is that of the alternate, who will serve only in the absence of the principal at the meeting of the Committee.

MINING BRANCH COUNCIL: Newell G. Alford, Alford-Morrow and Assoc., Pittsburgh, Pa. (J. R. Van Pelt, Battelle Memorial Institute, Columbus, Ohio); Grover J. Holt, Cleveland-Cliffs Iron, Co., Hibbing, Minn. (J. Murray Riddell, Michigan College of Mining and Technology, Hougton, Mich.)

METALS BRANCH COUNCIL: C. H. Lorig, Battelle Memorial Institute, Columbus, Ohio (G. B. McMeans, Kaiser Steel Corp., Fontana, Calif.).

PETROLEUM BRANCH COUNCIL: R. W. French, Sohio Petroleum Co., Cleveland, Ohio (John E. Sherborne, Union Oil Co. of Calif., Wilmington, Calif.).

EXECUTIVE COMMITTEE, COUNCIL OF SECTION DELEGATES: W. C. Leonard, American Smelting and Refining Co., Tacoma, Wash. (T. G. Chapman, College of Mines, University of Arizona, Tucson, Ariz.).

LEHIGH VALLEY SECTION: C. A. Warmkessel, Lehigh Portland Cement Co., Allentown, Pa. (H. R. Gault, Dept. of Geology, Lehigh University, Bethlehem, Pa.).

NEW YORK SECTION: P. Malozemoff, Newmont Mining Corp., New York, N. Y. (F. M. Cameron, St. Joseph Lead Co., New York, N. Y.).

SOUTHEAST SECTION: Garland Peyton, State Div. of Conservation, Atlanta, Ga. (E. H. Rose, Tennessee Coal, Iron and Railroad Co., Fairfield, Ala.).

CLEVELAND SECTION: K. H. Donaldson, Case School of Applied Science, Cleveland, Ohio (W. K. Bock, Cleveland, Ohio).

MINNESOTA SECTION: D. M. Davidson, E. J. Longyear Co., Minneapolis, Minn. (J. W. Van Evera, Crosby, Minn.).

UTAH SECTION: J. K. Richardson, Salt Lake City, Utah (P. J. Shenon, Salt Lake City, Utah).

SAN FRANCISCO SECTION: W. L. Penick, Western Precipitation Corp., San Francisco, Calif. (G. H. Playter, American Smelting and Refining Co., San Francisco, Calif.

SOUTHERN CALIFORNIA SECTION: J. E. Sherborne, Union Oil Co. of Calif., Brea, Calif. (G. D. Dub, Cypress Oil Co., Los Angeles, Calif.).

GULF COAST: S. E. Buckley, Humble Oil and Refining Co., Houston, Texas (A. W. Waddill, Houston Oil Field Material Co., Houston, Tex.).

EAST TEXAS: P. J. Lehnhard, East Texas Engineering Association, Kilgore, Tex. (R. K. Thies, Schlumberger Well Surveying Corp., Tyler, Tex.).

Members designated by President Haider: S. S. Clarke, chairman of the committee, The Eagle-Picher Co., Cardin, Okla. (F. E. Wormser, St. Joseph Lead Co., 250 Park Ave., New York 17, N. Y.). Earl R. Parker, 132 Hearst Mining Bldg., Berkeley, Calif. (E. M. Tittman, Box 1111, El Paso, Tex.). W. H. Geis, 437 S. Hill St., Los Angeles 13, Calif. (Howard C. Pyle, 1562 Royal Blvd., Glendale 7, Calif.).

The committee will welcome suggestions for the official slate for 1954. The following offices are to be filled: President-elect for 1954 (President for 1955), two Vice-Presidents, and six other Directors. ★ ★ ★

Oregon Section Enlarged

Revised bylaws for the Oregon Local Section, incorporating Cowlitz County, Washington, in its territory, have been approved by the board. The Section's area now is the entire State of Oregon, plus Cowlitz and Clark counties in Washington. ★ ★ ★

Visit the new offices of the Petroleum Branch, AIME, now located at 800 Fidelity Union Bldg., junction of Bryan, Pacific and Akard streets, Dallas, Tex.

Proposed for Membership, Petroleum Branch

Total AIME membership on Aug. 31, 1952, was 18,125; in addition 1,555 Student Associates were enrolled.

ADMISSIONS COMMITTEE

T. D. Jones, Chairman; Thomas G. Moore, Vice-Chairman; Harold S. Bell, F. W. Hanson, R. H. Chadwick, T. W. Nelson, J. H. Scaff, John T. Sherman, A. C. Brinkar, Ivan Given, C. A. R. Lambly, G. P. Lufjan, E. A. Prentis, and C. Leslie Rice, Jr.

The Institute desires to extend its privileges to every person to whom it can be of service, but does not desire as members persons who are unqualified. Institute members are urged to review this list as soon as possible and immediately to inform the Secretary's office if names of people are found who are known to be unqualified for AIME membership.

In the following list C/S means change of status; R, reinstatement; M, Member; J, Junior Member; A, Associate Member; S, Student Associate.

ARKANSAS
Magnolia — Redford, William Hamlet (A).

CALIFORNIA
Bakersfield — Dobeck, Howard Richard (J).
Buena Park — Govreau, Frederick Harrison (J).
Downey — Conrad, Martin Barcley (M).
Long Beach — Fielding, Herbert L. (M); Hamilton, Stanley Vincent (J).
Los Angeles — Morris, William Lind (R,M).
Newport Beach — Murphy, Bertram Hugh (R,J).
Taft — Severns, Jack Roger (M).

ILLINOIS
Mt. Vernon — Rue, Edward Evans (J).

KANSAS
Ellinwood — Bennett, Eugene Nelson (C/S-J-M).

LOUISIANA
Shreveport — Cook, Abner Wesley (J).

MINNESOTA
St. Paul — Slaby, Robert James (J).

MISSOURI
Kansas City — Riss, Richard Roland (A); Riss, Richard Roland, II (J).

OKLAHOMA
Norman — Maule, William Forrest (C/S-S-J).
Tulsa — Bennett, Arthur David (M); Campion, Frank Edward (J); Platt, George (J); Wasicek, Jerry James (R,C/S-S-J).

PENNSYLVANIA
Pittsburgh — Ingham, Albert Irwin (M).

TEXAS
Abilene — Evans, Andrew Jackson (M).
Austin — Roston, J. Paul (C/S-J-M).
Bishop — Longuist, William C., Jr. (J).
Clarkwood — Huff, Robert Benjamin (J).
Corpus Christi — George, Walter Goodwyn (J); Hicks, James Harold (A); Mueller, Joseph Paul (R,J); Rye, William C. (A).
Dallas — Moses, Phillip Lyle (J); Rust, Carl F. (M).
Falfurrias — Hansen, Alvin Peter (J).
Gainesville — Crain, Leon Ligon (J).
Houston — Abrams, Albert (J); Cook, Harold Lee, Jr. (M); Markham, Harold B. (M); Pate, William (J); Randall, Robert V. (M).
Kermit — McKaskle, Henry Gordon (J).
Kilgore — Davis, Bowen Monroe (A).
Kingsville — Custer, Robert Jackson, Jr. (J).
Longview — Petty, Jewel A. (C/S-S-J).
Midland — Griffith, William Franklin, Jr. (J); Locke, L. C. (M); McClellan, Johnny B. (J); Orman, Freeman L. (M); Qualia, Charles Francis (J); Ramsey, Dayton Earl (R,C/S-S-J); Schalk, Thomas S. (J); Sehnert, Harold Glen, Jr. (A); Teddlie, James E., Jr. (J).
Odessa — Hewitt, Donald Eugene (J); Hippard, Robert M. (M); Holten, Joseph Thomas, Jr. (J); Kastner, Donald L. (M); McLaughlin, James Dozier (J); Ormond, James Franklin (A).
Refugio — Slack, Jack Lewis (J).
Seminole — McElroy, Paul DeValle (J).
Vega — McKendree, Bishop D. (J).

MEXICO
Mexico, D. F. — Ruiz, Rodolfo Montalvo (J).
★ ★ ★

Institute Publications For 1953 Announced

Pursuant to Article X of the by-laws of the AIME, the following information is hereby given as to the "conditions, prices, and terms under which the various classes of Members, and Student Associates, severally, shall be privileged to obtain publications of the Institute during the ensuing year."

Publications authorized for issue in 1953 includes the following: MINING ENGINEERING, published monthly, containing material, including technical papers, of interest to those engaged in exploration, mining geology and geophysics, and metal, non-metallic, and coal mining and beneficiation, and fuel technology. The JOURNAL OF METALS, published monthly, containing material, including technical papers, of interest to those engaged in nonferrous smelting and refining, iron and steel, and physical metallurgy. The JOURNAL OF PETROLEUM TECHNOLOGY, published monthly in Dallas, containing material, including technical papers, of interest to those engaged in petroleum and natural gas drilling and production.

Annual subscriptions to any one of the above journals will be provided all members in good standing without further charge. (A member ceases to be in good standing if current dues are not paid by April 1). If more than one of the monthly journals is requested, $4 extra will be charged for an annual subscription, or 75c for single copies of regular issues and $1.50 for special issues. The nonmember subscription price for each journal is $8 in the Americas; foreign, $10, and for single issues $1 for regular issues and $2 for special issues. Student Associates will be entitled to the same privileges for all publications as members. AIME members subscribing to more than one of each of the three monthly journals will be billed at the nonmember rate of $8 per year, domestic; $10 foreign, for the extra subscription(s).

Three volumes of *Transactions* are authorized for 1953 publications, as follows: No. 193, Mining Branch; No. 194, Metals Branch; and No. 195, Petroleum Branch. These volumes will be available to members at $3.50 each for a first copy if paid for in advance with dues; otherwise at the nonmember rate of $7 less 30 per cent. Nonmembers $7 in the United States; foreign $7.50.

Special volumes now planned for publication in 1953 include the following: 1. *Open Hearth Proceedings*, price to AIME members $7, nonmembers $10; 2. *Blast Furnace, Coke Oven, and Raw Materials Proceedings*, AIME members $7, nonmembers $10; 3. *Electric Furnace Steel Proceedings*, AIME members $7; nonmembers $10; 4. *Dislocations in Metals* (price to be announced). 5. *Statistics of Oil and Gas Development and Production*, covering data for year 1951, members $5; nonmembers $10; 6. *Statistics of Oil and Gas Development and Production*, covering data for the year 1952, members $5, nonmembers $10; 7. *Symposium on Gasification and Liquefaction of Coal;* price $6 less 30 per cent to members; 8. *Problems of Clay and Laterite Genesis;* price $6 less 30 per cent to members.

If dues are paid subsequent to Jan. 31, back issues of Institute publications will be supplied only if adequate stocks are on hand. A member may not receive a volume of *Transactions*, or a special volume, in lieu of a monthly journal, free of charge on membership. Members in arrears for dues are not entitled to special members' prices for publications.

Rocky Mountain members may have their choice of an annual subscription to one of the monthly journals on request. ★ ★ ★

Visit the new offices of the Petroleum Branch, AIME, now located at 800 Fidelity Union Bldg., junction of Bryan, Pacific and Akard streets, Dallas, Tex.

New AIME Directory To Be Mailed in January

A complete directory of AIME members, with alphabetical and geographical listing in the form given in the 1948 Directory, but with Divisional membership also indicated, will be mailed with the January issues of the three journals. Publication had been scheduled with the December issues, but completion of the Flexoprint installation for publication of the volume was not completed until mid-November, and to have issued the book with the December issues would have involved a charge for overtime that did not seem justified. A large special issue of MINING ENGINEERING and an unusually early mailing date for the JOURNAL OF METALS in December were contributing factors to the postponement. ★ ★ ★

Members Not Interested In AIME Name Change

All discussions regarding any suggested change in the name of the Institute, to make the name more all-inclusive as regards the various classifications of professional membership, have indicated that there is no particular desire for any change. The Petroleum Branch, at the Houston meeting, suggested that the matter be dropped. No enthusiasm has arisen for the name "American Institute of Mineral Engineers." "American Institute of Mining, Metallurgical and Petroleum Engineers" is too unwieldy. "American Institute of Miscellaneous Engineers" is only good for a laugh. One suggestion is perhaps worthy of consideration: On all letterheads, carry the names of the ten divisions of the Institute. The matter probably will be discussed by the Council of Section Delegates at the Los Angeles meeting and finally disposed of by the Board at its meeting on Feb. 17, 1953. ★ ★ ★

The annual business meeting is scheduled to be held Tuesday, Feb. 17, at the Statler Hotel in Los Angeles, at 4 p.m.

ADVANCE AIME MEETING CALENDAR

	1953	1954
AIME Annual Meeting	Feb. 15-19 Statler Hotel Los Angeles	Feb. 14-18 Statler Hotel New York
AIME Fall Meeting	El Paso	
Petroleum Branch Fall Meeting (Mid-Continent)	Oct. 18-21 Baker and Adolphus Hotels, Dallas	San Antonio, Tex.
Regional Meeting, Pacific Petroleum Chapter	Oct. 1-2 Ambassador Hotel Los Angeles	Not determined

Employment Notices

The JOURNAL will post notices of men and jobs available. Companies and AIME members are invited to use this space, for which there is no charge. Except as noted below, address replies to: Code (appropriate number), JOURNAL OF PETROLEUM TECHNOLOGY, 800 Fidelity Union Bldg., Dallas 1. Show return address on envelope. These replies will be forwarded unopened and no fees are involved.

Replies to the positions coded Y7835, Y7768, and Y7715 below should be addressed to: Engineering Societies Personnel Service, 8 West 40th St., New York 18, N. Y. The ESPS, on whose behalf these notices are published here, collects a fee from applicants actually placed.

PERSONNEL

♦ Engineer, 33, married, one child, desires change of position. Graduate with seven years' oil field experience in production, drilling workover and general petroleum engineering. Preference is for supervisory position in production and/or drilling operations, or will accept position in engineering if proffered. Code 175.

♦ Petroleum engineer, University of Oklahoma, age 31, four years' experience drilling, well completions, gas compression and transmission, equipment sizing and purchasing. Interested in small active independent in Texas or Rocky Mountain region. Presently employed with drilling and producing company. Code 176.

♦ Geologist, age 36, master's degree, desires to relocate with small active independent preferably in Rocky Mountains or Texas. Seven years' diversified experience in all phases petroleum geology and well engineering in Southwest Texas, Mississippi, Louisiana and Alabama. Presently employed by large independent. Code 177.

♦ Geologist, MS, age 34, 12 years' varied experience in U. S., Canada, Europe, South America, Africa. Surface and subsurface background. Desires foreign assignment in supervisory capacity. Code 178.

♦ Graduate petroleum engineer, 10 years' varied administrative, operational and engineering experience with major. Now in responsible supervisory position. Interested in change to responsible position with smaller firm or independent. Code 179.

♦ Graduate petroleum engineer with two years' training in reservoir engineering, including some PVT studies. Experience in gas-distillate well production testing, reserve estimation and valuation. Presently employed with small independent. Prefer location in Houston, Tex. Married, age 25. All offers acknowledged. Code 180.

POSITIONS

♦ Maintenance design engineer, 25-30, chemical or mechanical engineering graduate, with chemical or oil refining experience, to prepare plans and procedures covering plant maintenance and alteration in oil refinery. Salary, $4,800-$6,000 a year. Location, northern New Jersey. Y7835.

♦ Sales engineer, 35-40, with some knowledge of lubrication problems in the mill and factory trade. Will do some engineering as well as sales. Salary plus commission. Location, New York, New Jersey and Conecticut. Applicants from these areas preferred. Y7768.

♦ Design draftsman with piping experience, to lay out systems for oil and gasoline bulk terminal. Salary, $5,200-$6,500 a year. Location, Newark, N. J. Y7715. ★ ★ ★

Bills for AIME Dues Now Being Mailed

Pursuant to Article II, Section 2, of the Bylaws of the AIME, notice is hereby given that dues for the year 1952 are payable Jan. 1, 1953, as follows: Members and Associate Members, $20; Junior Members for the first six years of Junior Membership, $12 and thereafter, $17; Student Associates (including an annual subscription to a monthly journal), $4.50.

Mailing of dues bills began in October and will be completed before the end of the year. Prompt payment will assure uninterrupted receipt of the publications desired in 1953. If, for any reason, a bill is not received within a reasonable time after the last mailing date, Dec. 31, 1952, headquarters should be notified. ★ ★ ★

Visit the new offices of the Petroleum Branch, AIME, now located at 800 Fidelity Union Bldg., junction of Bryan, Pacific and Akard streets, Dallas, Tex.

Economics of Cycling

Continued from Page 23, Section 1

starts at 12c per MCF and is escalated .2 cent per MCF per year.

The calculations made indicated that the following conclusions could be drawn:

1. The price of gas has a large effect upon the increased liquid recovery resulting from cycling due to its influence on the abandonment pressures which can be economically achieved under primary depletion.
2. Cycling operations are most attractive from an economic standpoint if conducted at rates considerably in excess of primary gas sales rates.
3. The presence of an escalator clause in the gas sales contract greatly increases the economic incentive for cycling.
4. Costs incurred in cycling operations are not justified from the standpoint of increased liquid recoveries alone, except in reservoirs with fairly rich gas and high retrograde losses. ★ ★

Holman and Muskat To Receive Medals

Eugene Holman has been named to receive the Rand Medal for distinguished achievement in mining administration. Holman is president of the Standard Oil Co. (N.J.) and will receive the award at the forthcoming Annual Meeting in Los Angeles. Another member of the Petroleum Branch, Morris Muskat, will likewise be honored at the Annual Banquet, when he will receive the Anthony F. Lucas Medal. This is given for distinguished achievement in improving the technique and practice of finding and producing petroleum. Muskat is director of the physics division of the Gulf Research and Development Co., Pittsburgh. ★ ★ ★

Board Sets Dues Rate

At its Sept. 7 meeting, the AIME Board voted to revise the first two sentences of Art. II, Sec. 2, of the Bylaws to read as follows: "Until otherwise determined by the Board of Directors of the Institute, the dues of Members and Associate Members shall be $20 per annum, and dues of Junior Members shall be $12 per annum for the first six years of membership, and thereafter $17. Dues shall not be required of either Honorary or Senior Members." ★ ★ ★

1953 Official Nominees Declared Elected

No supplementary nominations for AIME officers for 1953 having been received, the Board of Directors, at its meeting on Nov. 19, declared the official selections of the Nominating Committee elected without the formality of a ballot. The names of the elected officers were published in the July issues of the journals, with biographical sketches. They are as follows: President-elect, Leo F. Reinartz; Vice-Presidents, Augustus B. Kinzel and Lloyd E. Elkins; Directors, Philip D. Wilson, Hjalmar W. Johnson, Edwin L. Oliver, Elmer H. Isern, Philip Kraft and Gail F. Moulton. One additional director for a one-year term, to fill out the unexpired term of Reinartz as Vice-President, remains to be appointed by the board at its meeting on Feb. 17, 1953. ★ ★ ★

Necrology

Donald Adair Powell (Member 1918) died Oct. 12 after an illness of several months. He was born in Columbus, Ohio, and attended Ohio State University. After several years as a mining engineer in the silver mines at Guanajuato, Mexico, he joined Atlantic Refining Co. in Tampico, where he was geologist and field superintendent from 1921 to 1929. He then joined Drilling and Exploration Co., serving in Canada, Michigan and Pampa, Tex. In 1938, he was transferred to Hobbs, N. M., where he resided until his death, and was in charge of Panhandle, West Texas and New Mexico operations for the company. He had been vice-president and director of the company since 1937.

Harold Edward Boyd (Member 1920) died June 24. Born in San Jose, Calif., he was educated at Leland Stanford University. He worked as a petroleum geologist with the Caribbean Petroleum Co. in Venezuela from 1912 to 1915, when he returned to the United States, and served with various companies in geological and engineering positions for the next four years. From 1919 to 1933 he was with the Henry L. Doherty Co., and later joined the Dominion Natural Gas Co. in Buffalo, N. Y. He then moved to California, and was for several years a consulting geologist there. At the time of his death he resided in East Lansing, Mich., where he had been employed with the Panhandle Eastern Pipe Line Co.

Frederick B. Heath, Jr. (Member 1947) died July 25 in a hospital at Tulsa, Okla. He was born in Reading, Pa., in 1905, and was educated at Syracuse University and the University of Pittsburgh. From 1928 to 1946 he was with the Natural Gas Production Dept. of Columbia Gas and Electric Corp. and Columbia Engineering Corp. in Pittsburgh, Pa. In 1946 he became a gas engineer in the Manufacturing Department of Stanolind Oil and Gas Co. in Tulsa. He later became project engineer of the gas development section for the company.

Henry May Dawes (Member 1936) died Sept. 29 in a hospital in Evanston, Ill. He was born in 1877 in Marietta, Ohio, and was graduated from Marietta College in 1896. In 1906 he became secretary-treasurer of Dawes Brothers, Inc., in which he was associated with his brothers. He was later president of the Southwestern Gas and Electric Co., and from 1924 to 1947 was president of the Pure Oil Co. Since 1947 he had been chairman of the executive committee of the company. He was also a director of the American Petroleum Institute.

Julius A. Heeren (Member 1943) died at a hospital in Denver, Colo., on Nov. 15, at the age of 47. He was associated professor of petroleum engineering at the Colorado School of Mines.

John Hudson Hall (Associate Member 1943) died Aug. 14. He resided in New York, N. Y.

★ ★ ★

33 Members to Receive Legion of Honor Insignia

Thirty-three members of the AIME "Class of 1903" will be presented with the Legion of Honor insignia at the Annual Banquet of the Institute in Los Angeles' Statler Hotel next February. The awarding of the insignia will commemorate their achievement of 50 years of membership in the AIME. The following members will receive the honor:

ANDERSON, A. J.
Mina, Nev.

AVERY, JOHN
Avery & Anderson
360 Collins St.
Melbourne, Vic., Australia

BRUCE, JAMES L.
Cyprus Mines Corp.
1206 Pacific Mutual Bldg.
Los Angeles 14, Calif.

CAUTLEY, A. O.
14 Highfield Rd.
Northwood, Middlesex, Eng.

CLAUDET, H. H.
R.R. 5, Gordon Head
Victoria, B. C., Can.

CLEVENGER, GALEN H.
Box 137
Centerville, Mass.

CROMWELL, ROBERT H.
Electro Manganese Corp.
519 Main St.
East Orange, N. J.

DESLOGE, FIRMIN V.
Smokey Oil Co.
506 Olive St.
St. Louis, Mo.

DU RELL, CHARLES TERRY
University Club
Los Angeles, Calif.

GREENIDGE, S. M.
Texas Pacific Coal and Oil Co.
Box 2110, Fort Worth, Tex.

HAMILTON, ARTHUR L.
Sugar Hill,
Lisbon, N. H.

HOOPER, FRANK C.
Barton Mines Corp.
North Creek, N. Y.

HUSTON, HARRY L.
2901 Columbia St.
Vancouver, Wash.

JEWETT, FRANK G.
1816 S. Fremont Ave.
Minneapolis, Minn.

LANDERS, W. H.
Box 105, Monterey, Calif.

LEITH, CHARLES K.
Science Hall, Univ. of Wisconsin
Madison, Wis.

LEVENSALER, LEWIS A.
Apt. 308, 666 Post St.
San Francisco, Calif.

LINCOLN, FRANCIS C.
261 I Street
Chula Vista, Calif.

LUNT, HORACE F.
507 Boston Bldg.
Denver, Colo.

MARCY, FRANK E.
3910 Henry St.
San Diego, Calif.

MCCLELLAND, J. F.
Phelps Dodge Corp.
40 Wall St.
New York, N. Y.

MILLER, EMORY T.
436 Passaic Ave.
Passaic, N. J.

MOULTON, H. G.
70 Pine St.
New York 5, N. Y.

NUTTER, EDWARD H.
Saratoga, Calif.

RICHARDSON, WARREN V.
701 Marsh Ave.
Reno, Nev.

SALSICH, LEROY
912 Alworth Bldg.
Duluth 2, Minn.

SHERMAN, GERALD
Columbia Univ. Club
4 West 43 St.
New York, N. Y.

THROCKMORTON, HOWARD
210 W. 7th St.
Los Angeles 14, Calif.

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Broken Hill South, Ltd.
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Melbourne, Vic., Aus.

WARTENWEILER, FRED
33 Rosebank Rd.
Dunkeld, Johannesburg, S. Africa

WITTENOOM, CHARLES H.
Middleton Beach
Albany, Western Aus.

WOLF, HARRY J.
420 Madison Ave.
New York 17, N. Y.

WRAITH, WILLIAM
Apt. 911, Cooper Arms
455 E. Ocean Ave.
Long Beach 2, Calif. ★ ★ ★

Book Reviews

The following books are available in the Engineering Societies Library, and may be borrowed by mail by AIME members for a small handling charge. The library also prepares bibliographies and translations, and provides search, photostat and microfilm services. Address inquiries to Ralph H. Phelps, Director, Engineering Societies Library, 29 West 39th St., New York 18, N. Y.

Symposium on Surface and Subsurface Reconnaissance

American Society for Testing Materials, Philadelphia 3, Pa. (S.T.P. No. 122) 1952. 228 pp., graphs, charts, illus., tables, 9 x 6 in., paper. $3.00.

A group of 15 papers dealing with geological, pedological, airphoto, or geophysical interpretations of data on earth formations and deposits, over half of the material being devoted to geophysical methods. The object of the symposium was to establish a groundwork for defining the applications and limitations of these major approaches to reconnaissance with respect to the accuracy of their results. The panel discussions on the papers are included.

Charting Statistics

By Mary Eleanor Spear. McGraw-Hill Book Co., Inc., New York, 1952. 253 pp., illus., charts, graphs, 9¼ x 6¼ in., bound. $4.50.

A liberally illustrated textbook employing drafting room methods of charting for practical graphic presentation of statistical data. Various interpretations of the same tables are used to illustrate the types of charts applicable to the given table of facts. Among the varieties discussed are line, surface, column, bar, map, and flow charts.

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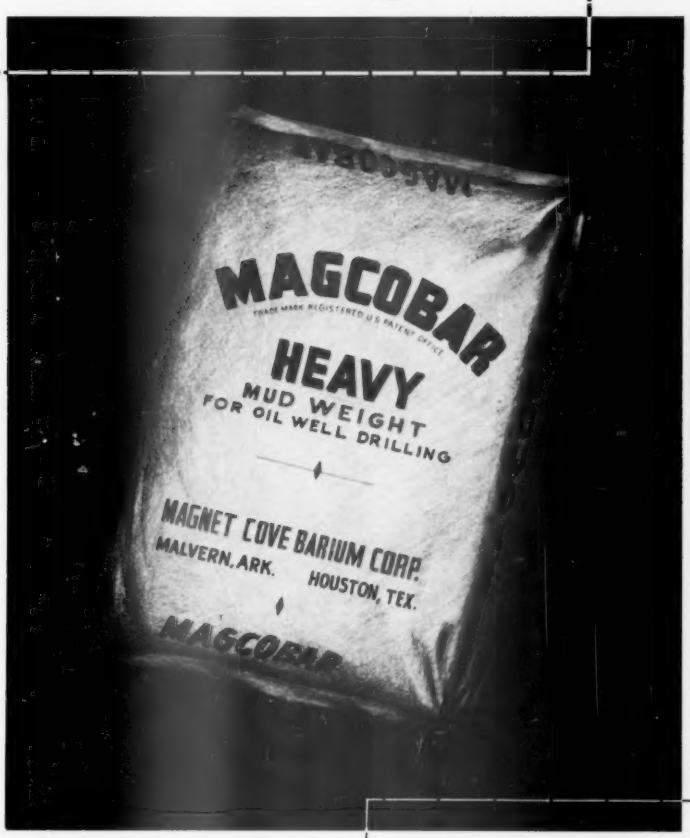

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